RESPONSE TO NRC QUESTIONS ON FORT CALHOUN'S REFINED SEISMIC SPECTRA

Prepared for:

U.S. Nuclear Regulatory Commission

Prepared by:

Omaha Public Power District

October 1990

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SECTION 1: INTRODUCTION

Omaha Public Power District (OPPD) has submitted Alternate Seismic Criteria for the Fort Calhoun Station to the NRC in December 1988. The proposed criteria covered piping and pipe supports, electrical raceways, HVAC and associated expansion anchor bolts. In conjunction with the criteria, refined seismic response spectra were generated and submitted to the NRC in February 1989.

In December 1989, OPPD received NRC's questions and comments pertaining to the criteria document. OPPD decided to pursue further licensing on refined spectra, piping (mainly the PVRC damping) and HVAC, and subsequently submitted responses to NRC's questions in July 1990. The latter submittal included the response to a question related to the generation of the refined seismic spectra , as requested by the NRC. In August 1990, OPPD received questions on the calculations related to the generation of the refined seismic spectra submittal in the form of Open Items (OI) and Requests for Additional Information (RAI) (Reference 1). The responses to the OI and RAI are included in the present report.

There are a total of forty OI and RAI related to the seismic spectra generation. The response to these questions is presented in Section 2 of the report. The NRC questions are grouped according to the corresponding document (a total of XI groups). For each group of OI and RAI (each group herein referred to as "Question"), the OI and RAI are repeated first and are followed by response. References are included in Section 3.

SECTION 2: RESPONSE TO NRC QUESTIONS

QUESTION I:

Document: Impell Corporation, "Generation of Artificial Time Histories," Calc. No. TH-1, Rev. 0, Job No. 1390-027-1355.

(1) OI:

(a) The Standard Review Plan (SRP) (NUREG-0800) recommends that the Power Spectral Density function (PSD) of an artificial time history used for a single time history analysis meet a target PSD spectrum (NUREG/CR-3509).

(b) The floor response spectra were calculated for a number of damping values ranging from 1 percent to 10 percent. To meet SRP requirements a check must be made that the response spectra of the artificial time history envelope the design response spectra for all damping values used in the response analysis.

(c) The SRP recommends that the stationary phase strong motion duration of the artificial time history should be between 6 and 15 seconds.

(2) RAI

(a) Provide the information that the intent of the SRP recommendations are met.

(b) Provide Impell's version of SIMQKE together with its user's manual.

RESPONSE TO QUESTION I:

(1) OI: (a) The PSD functions of the three artificial time histories (NS, EW and vertical) are plotted in Figures I.1 to I.3. The PSD function is computed as:

$$PSD(w) = |F(w)|^2 / (\pi T_D), \qquad (1)$$

where,

w = frequency,
$|F(w)|$ = Fourier amplitude evaluated over strong motion duration T_D, and,
T_D = strong motion duration (equal to 8.0 seconds)

PSD units are in^2/sec^3.

Plotted, in Figures I.4 through I.6, are the average PSD functions generated based on ±20% averaging centered about each frequency. The average PSD functions confirm that there is no deficiency of power present over any frequency range.

The target PSD contained in NUREG/CR-3509 (Reference 13) was developed to be compatible with Regulatory Guide 1.60 spectra. The Fort Calhoun USAR design ground spectra, which were used in the soil-structure interaction (SSI) analyses, are not compatible to Regulatory Guide 1.60 spectra. Therefore, the PSD obtained from the Fort Calhoun time histories is not comparable to the PSD recommended in NUREG/CR-3509. The artificial time histories were developed according to SRP, Revision 1 recommendations (Reference 8), which do not include PSD provisions. All other enveloping provisions in the SRP, Revision 1, as discussed below in OI(b), are met by an ample margin.

(b) Checks were made in Impell Calculation THG-1 to verify that the response spectra obtained from the three artificial time histories (NS, EW and vertical directions) envelop the USAR ground spectra. The spectra checks were performed for 2% and 5% damping, since the USAR design ground spectra are available only for 0, 0.5, 2 and 5% damping. The results from the checks are also included, in Figures I.7 to I.12, which show that ample margin above the design ground spectra exists for all directional time histories and damping values.

In the SSE analysis, viscous damping was specified as 4% for the steel piles, 7% for bolted steel members, and 7% for concrete, according to Regulatory Guide 1.61 (Reference 10). Even though no component in the structural models has damping less than 4%, the spectrum enveloping checks were performed for 2% damping as well.

It is known from experience that, in general, if low damping time history spectra envelop low damping design spectra, high damping spectra derived from the same time history will envelop high damping design spectra as well. Therefore, the enveloping check with 5% damping is sufficient for damping ratios higher than 5%.

Based on the above, it is concluded that the time histories are conservative for all damping values considered in these analyses.

(c) The stationary phase strong motion duration of each of the three artificial time histories (NS, EW and vertical) is 8.0 seconds (Reference 4). This duration is in the range of 6 to 15 seconds, as recommended by the NRC in Reference 1.

(2) RAI: (a) Pertinent information are provided in the responses to OI (a), (b) and (c) above.

(b) The User's Manual of Impell's SIMQKE computer program is provided in this package as Attachment 1. The source code of the program is included in the User's Manual.

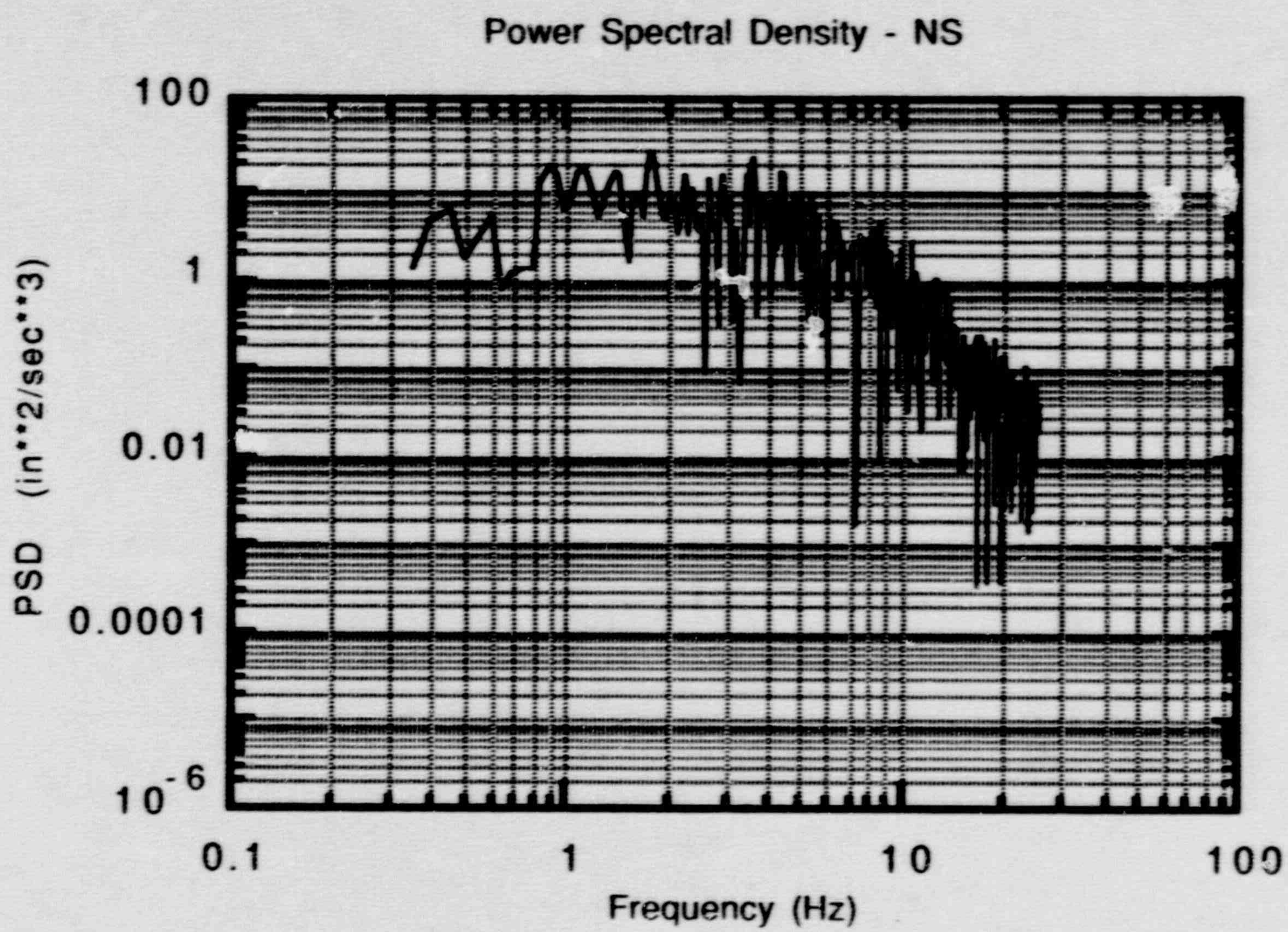


Figure I.1 - Power Spectral Density Function
Artificial Time History, NS Direction

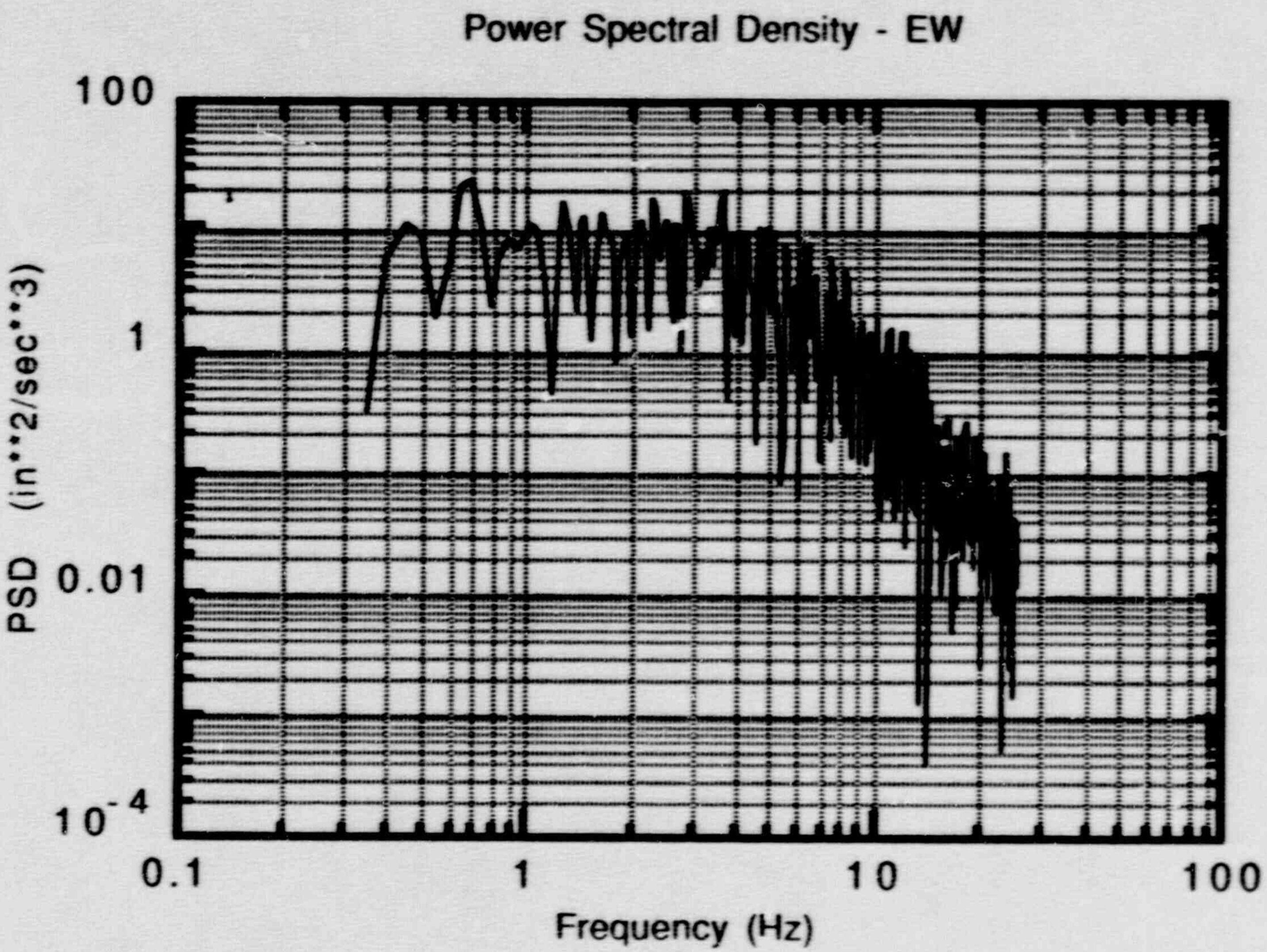


Figure I.2 - Power Spectral Density Function
Artificial Time History, EW Direction

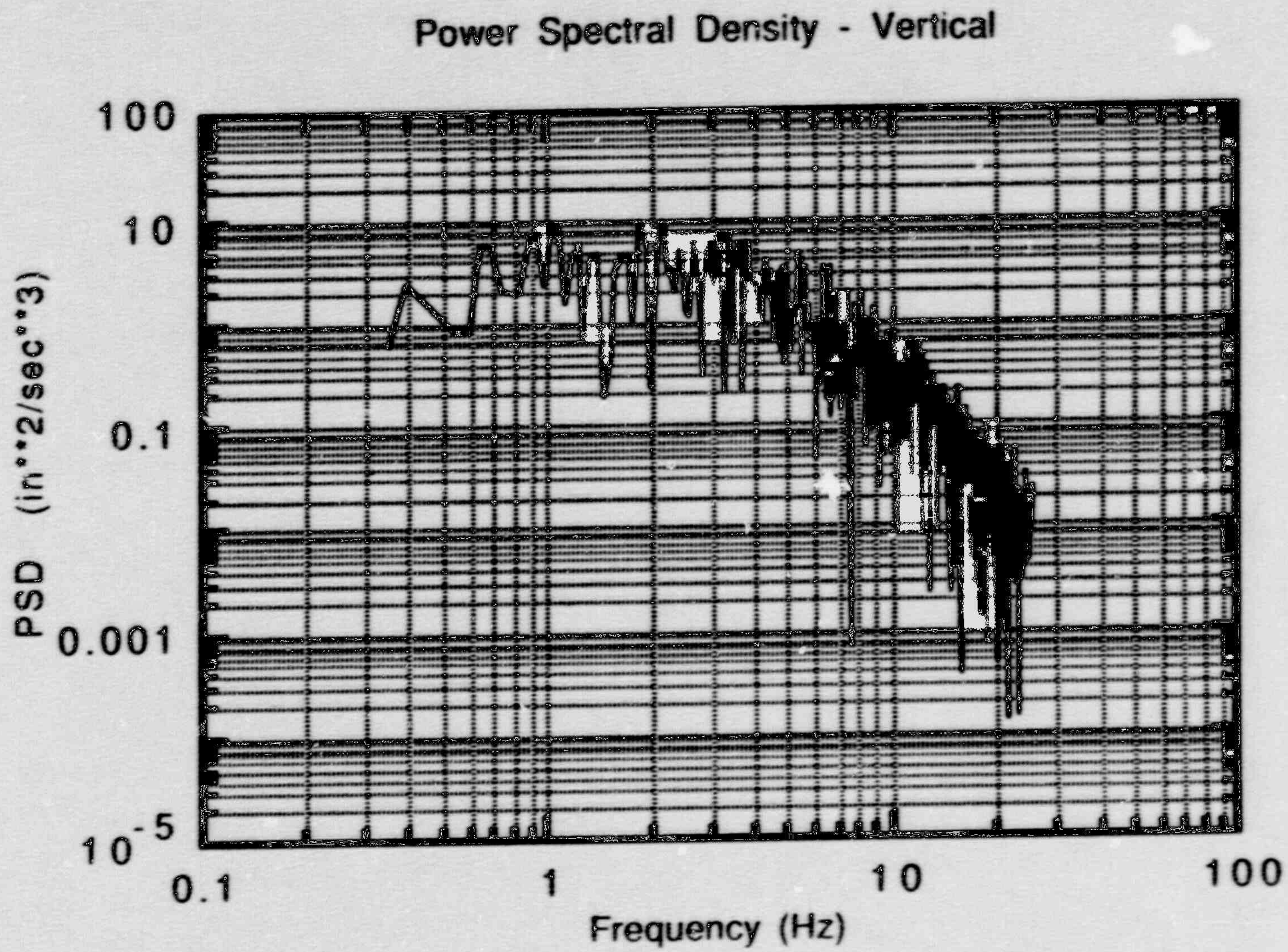


Figure I.3 - Power Spectral Density Function
Artificial Time History, Vertical Direction

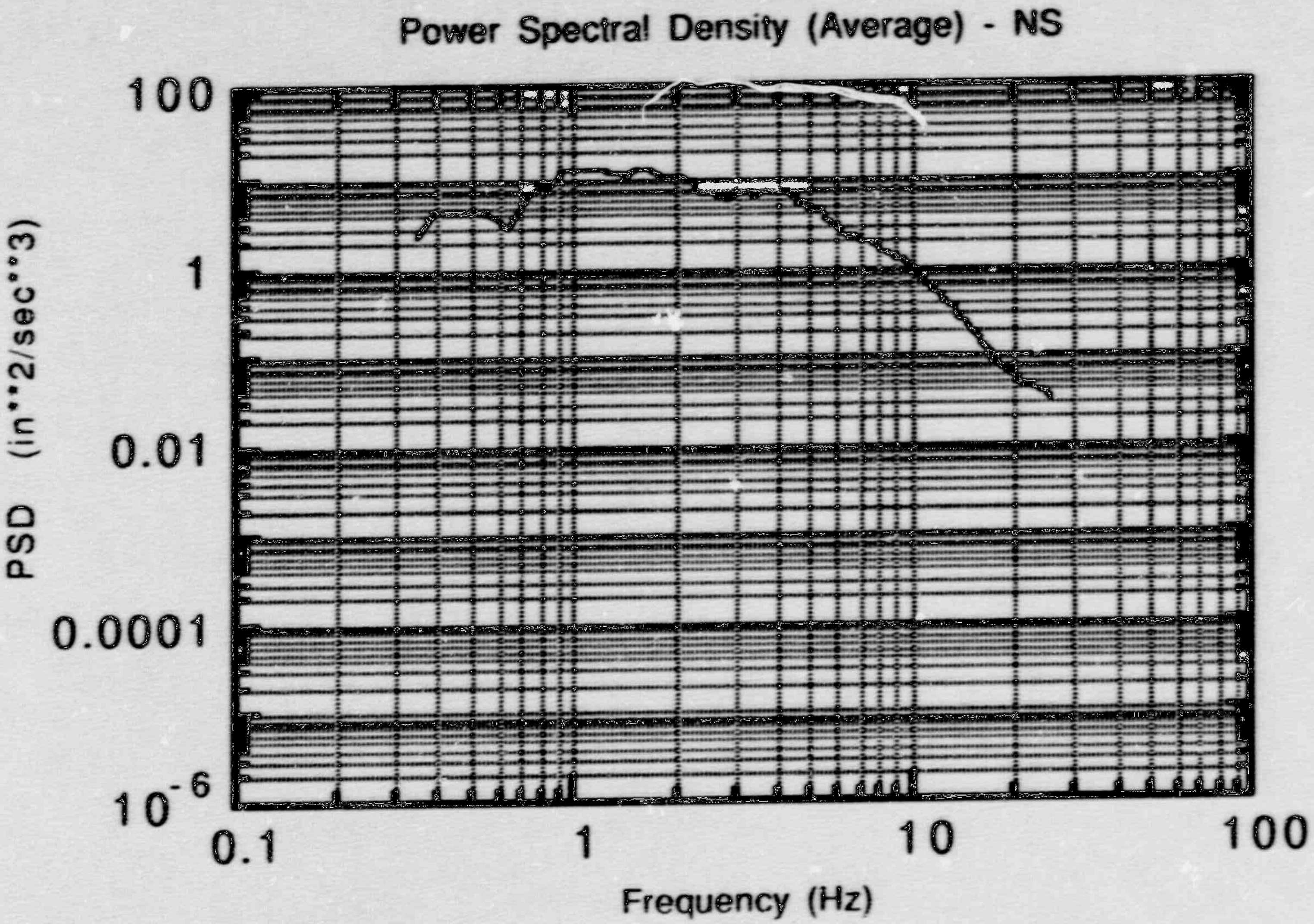


Figure I.4 - Average Power Spectral Density Function
Artificial Time History, NS Direction

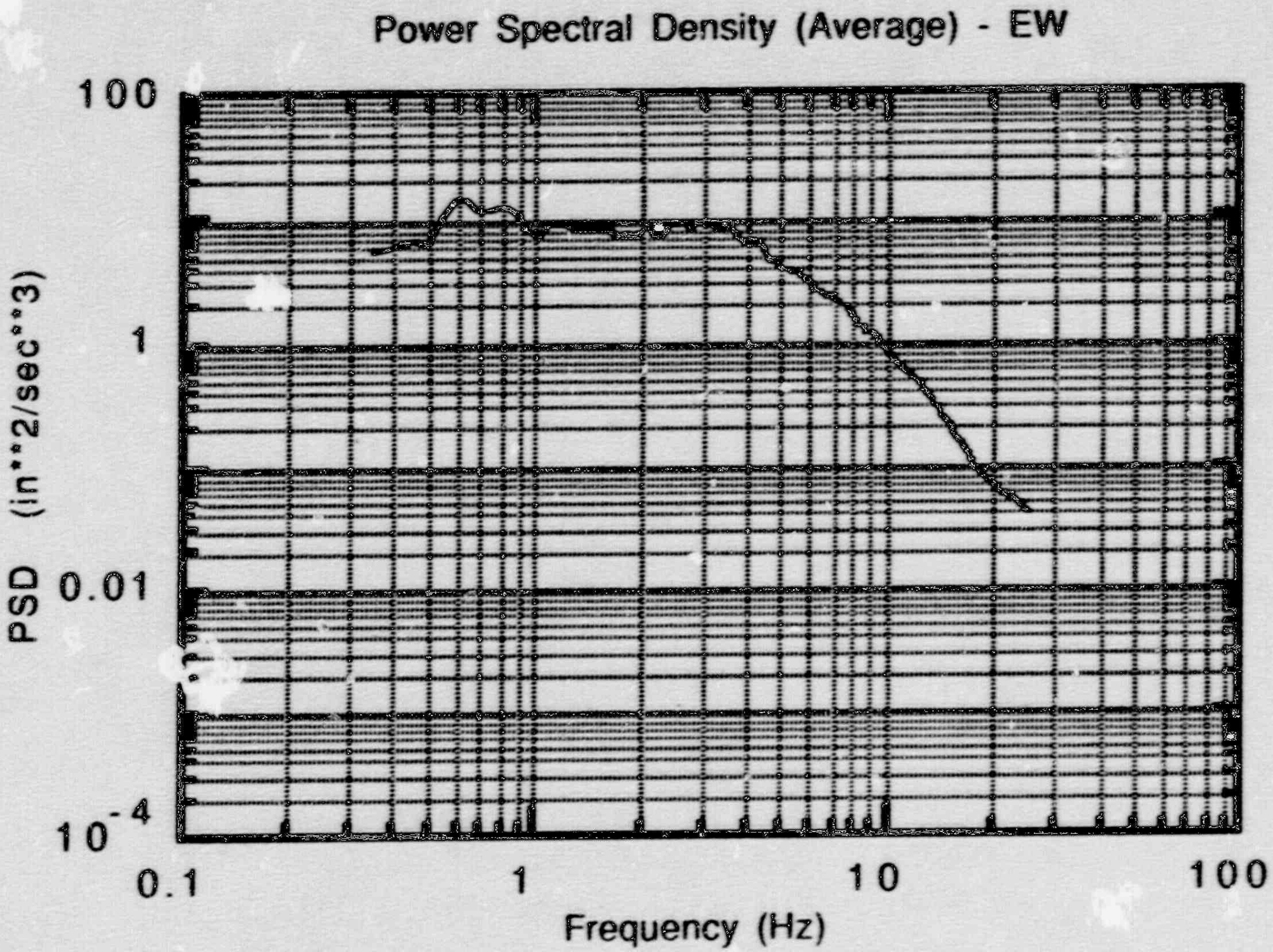


Figure I.5 - Average Power Spectral Density Function Artificial Time History, EW Direction

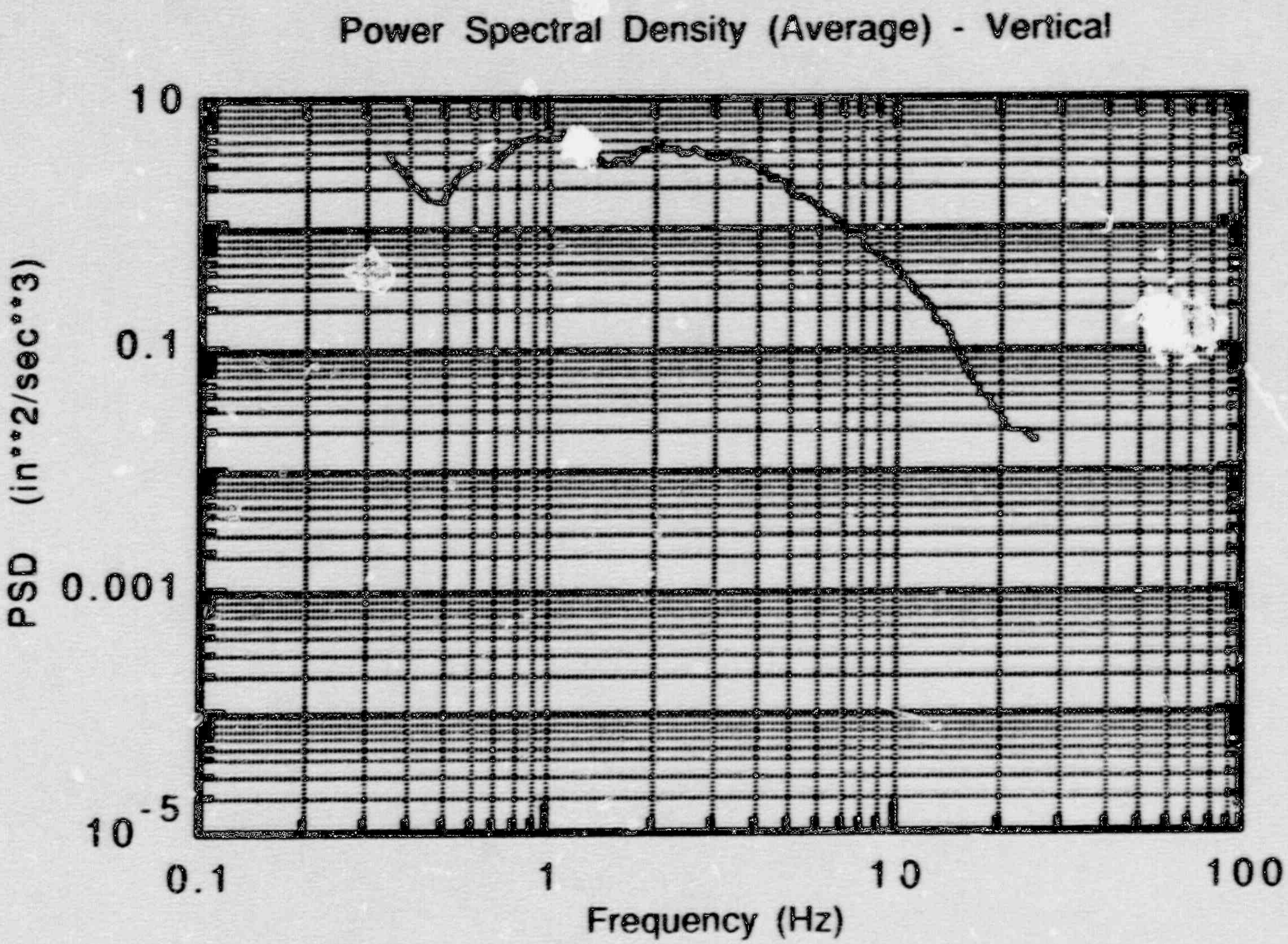


Figure I.6 - Average Power Spectral Density Function
Artificial Time History, Vertical Direction

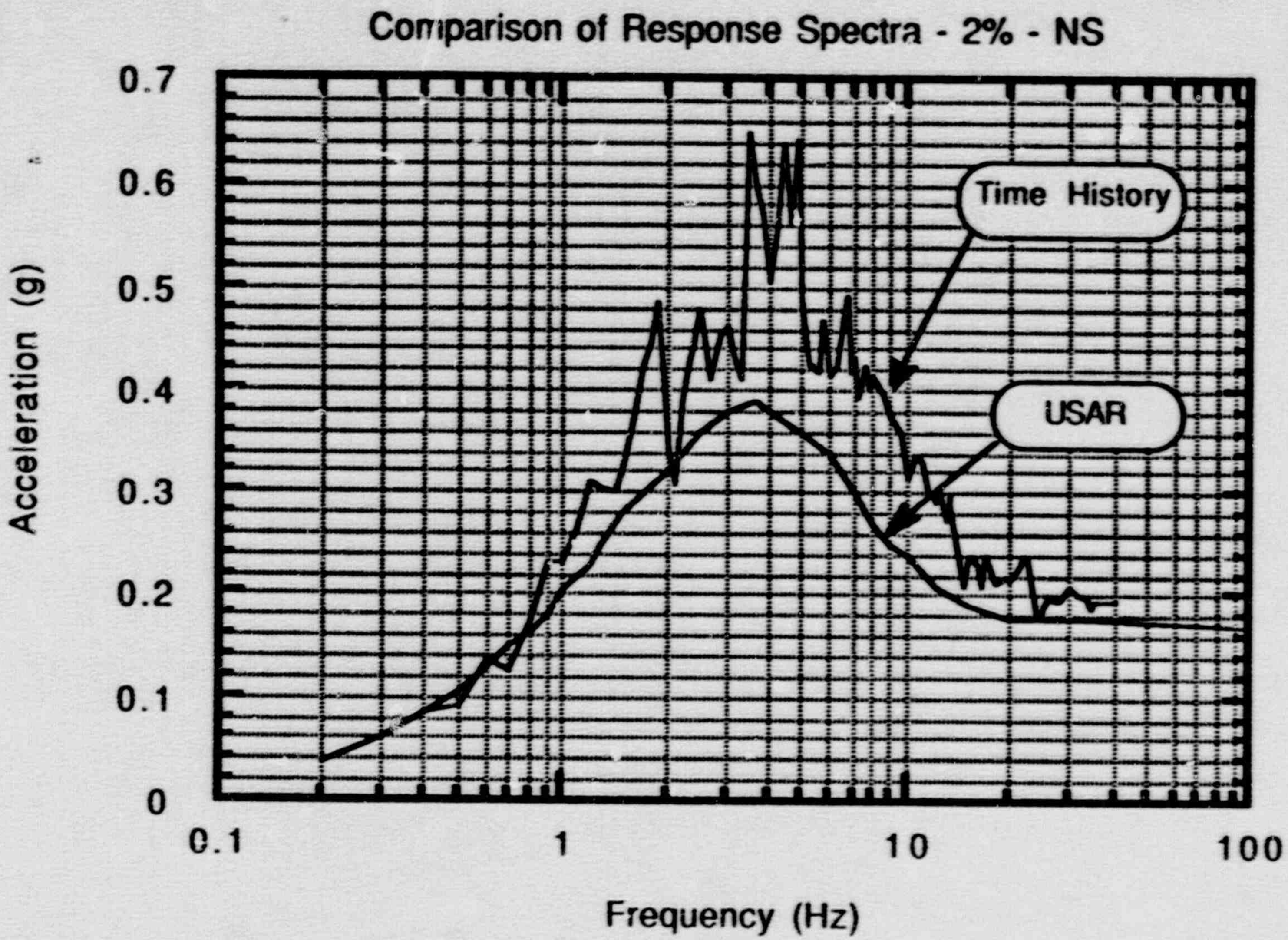


Figure I.7 - Comparison of Response Spectra (Time History vs. USAR)
NS Direction, 2% Damping

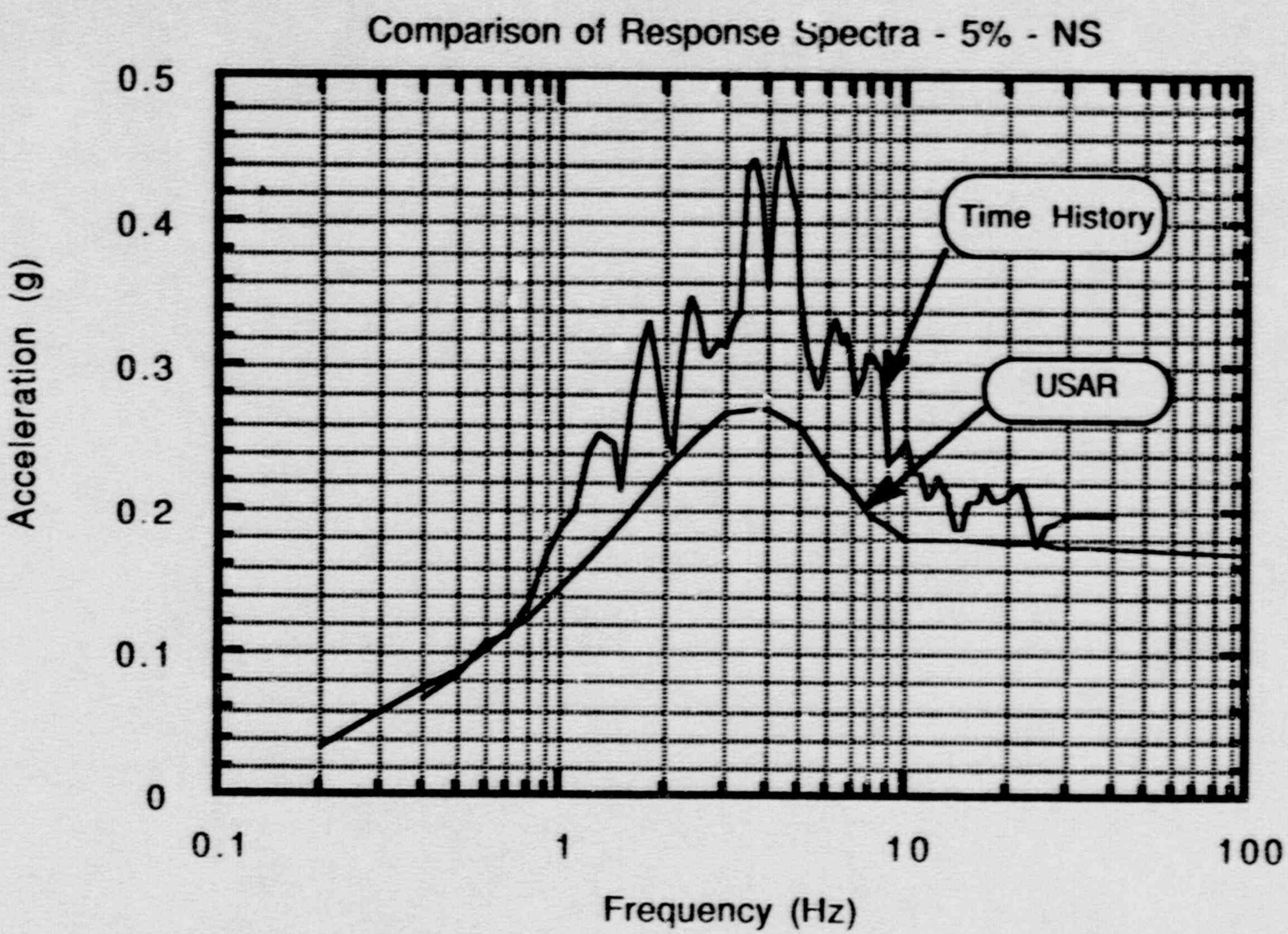


Figure I.8 - Comparison of Response Spectra (Time History vs. USAR)
NS Direction, 5% Damping

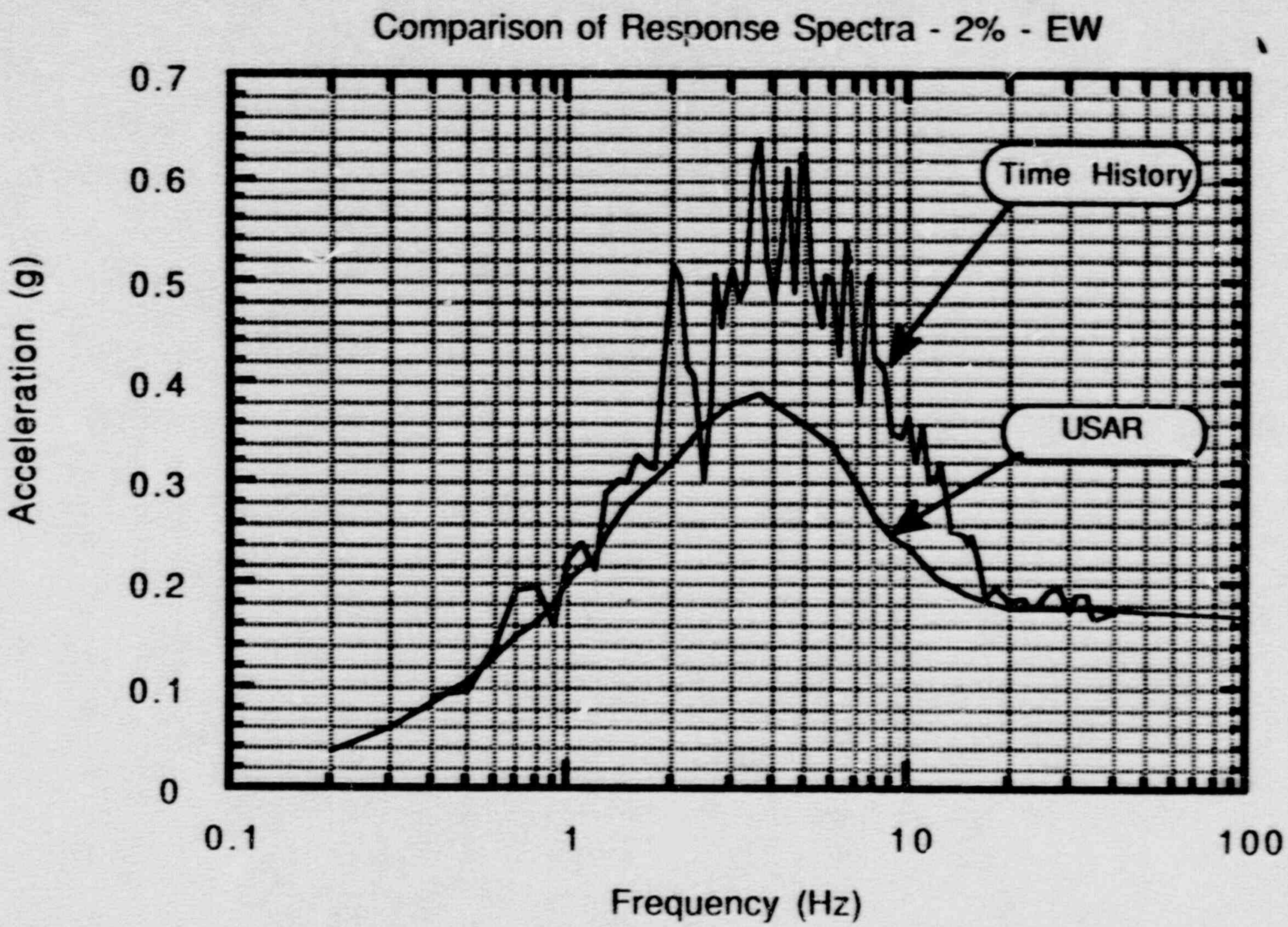


Figure I.9 - Comparison of Response Spectra (Time History vs. USAR)
EW Direction, 2% Damping

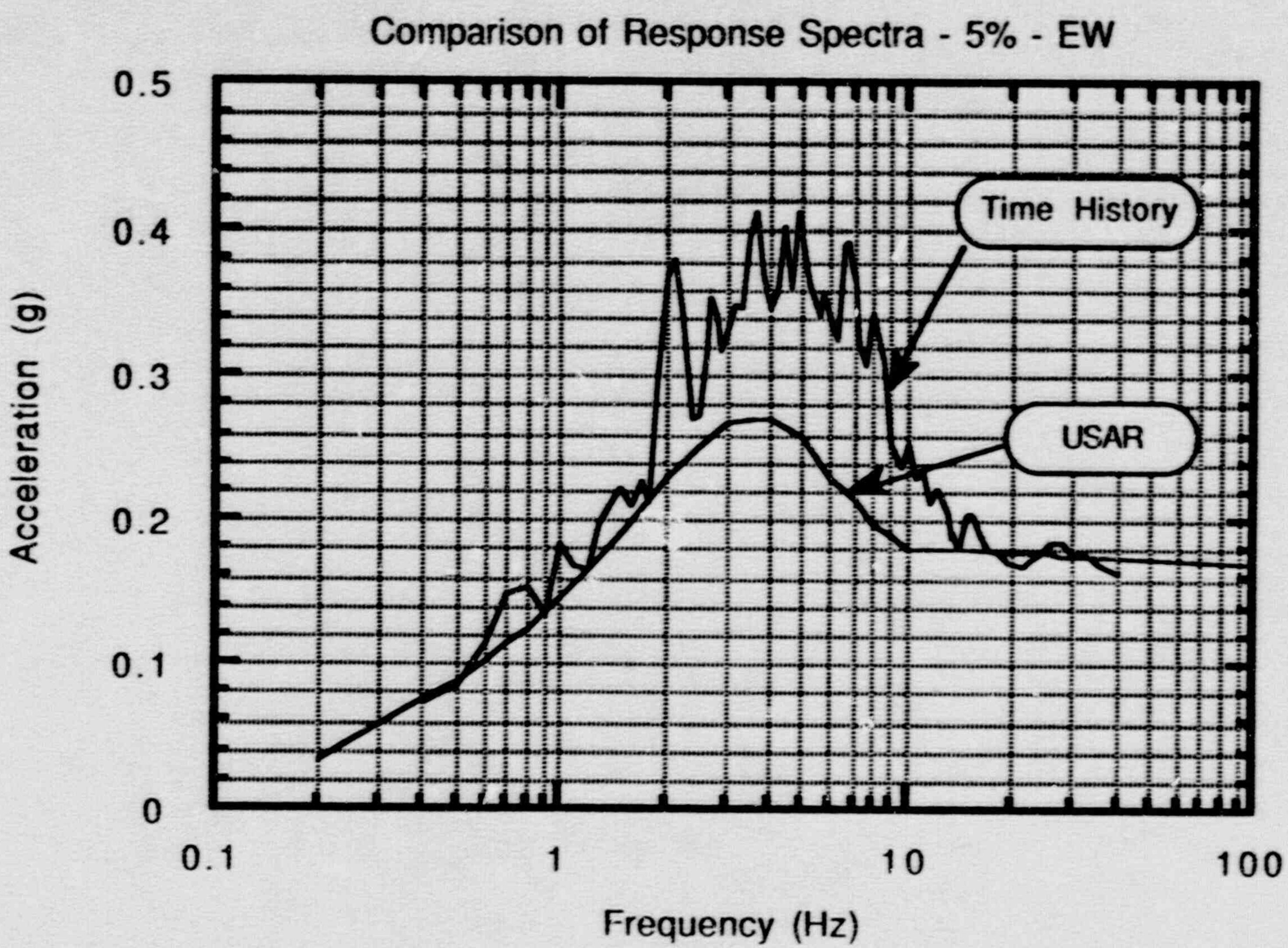


Figure I.10 - Comparison of Response Spectra (Time History vs. USAR)
EW Direction, 5% Damping

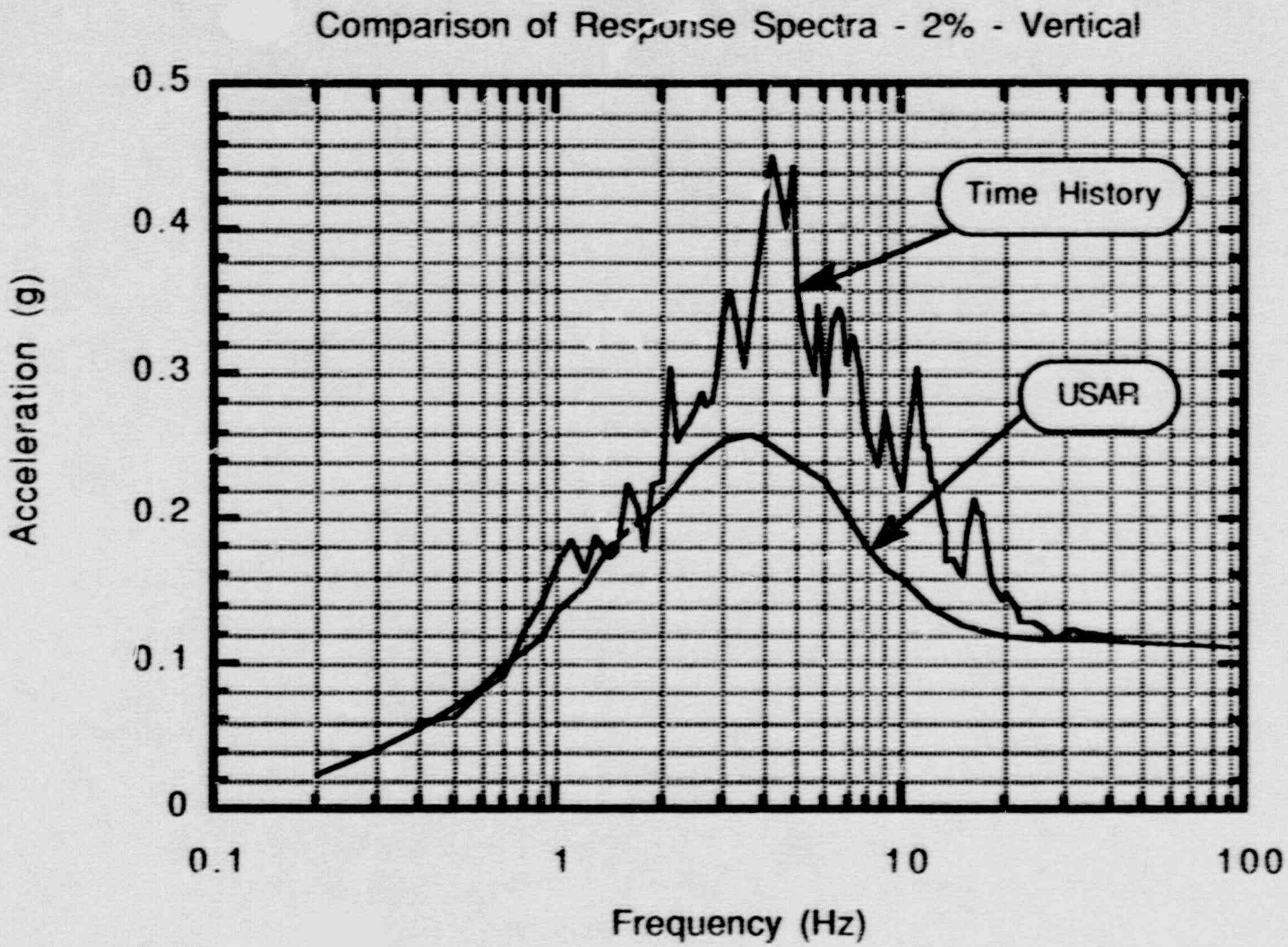


Figure I.11 - Comparison of Response Spectra (Time History vs. USAR) Vertical Direction, 2% Damping

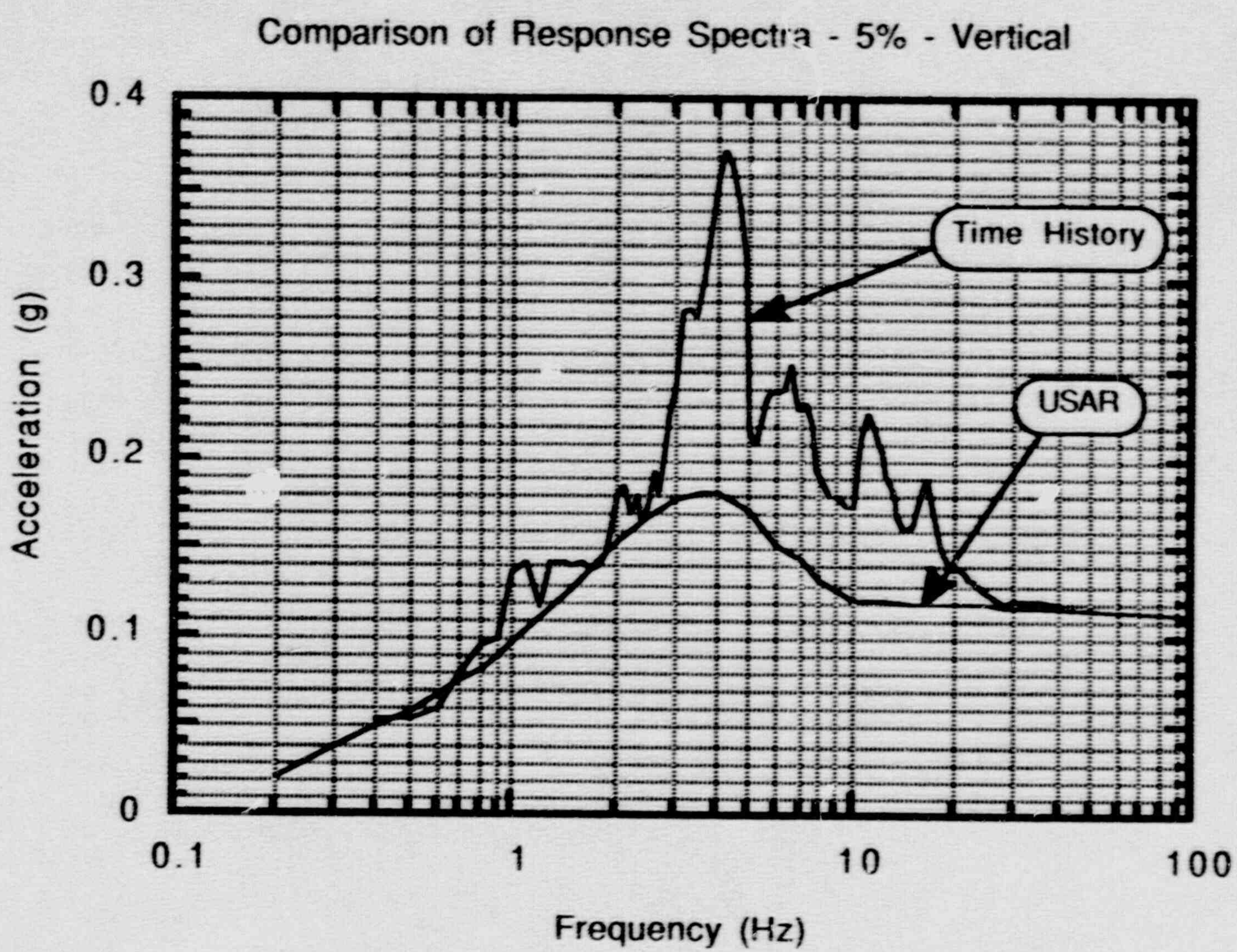


Figure I.12 - Comparison of Response Spectra (Time History vs. USAR)
Vertical Direction, 5% Damping

QUESTION II:

Document: Impell Corporation, User's Manual Rev. 0, Standard Computer Program CLASSI, Version 0.0, 1986.

(1) OI: (a) It appears that only the SSIN portion of the CLASSI computer program was used for the Fort Calhoun Soil Structure Interaction analysis (SSI).

(2) RAI (a) Provide discussion and verification of Impell's CLASSI version used in developing Ft. Calhoun's seismic criteria.

RESPONSE TO QUESTION II:

(1) OI: (a) The SSI analysis of Fort Calhoun's Reactor Building was performed in a two-step approach:

1. First, foundation impedances were computed using the computer program SASSI.

2. Secondly, the solution of the equations of motion of the coupled soil/structure system, and computation of response acceleration time histories were performed using the computer program CLASSI.

This approach was reviewed and licensed by the NRC during the Long Term Service (LTS) Program of Southern California Edison's SONGS-1 nuclear power plant (Reference 5).

In a conventional CLASSI analysis, the three CLASSI modules GLAYER, CLAF and SSIN (Reference 6) are executed sequentially in order to compute structural response. GLAYER and CLAF are used to generate foundation impedances. For Fort Calhoun, SASSI was selected to generate the foundation impedances because of SASSI's capabilities to model foundations with piles. Therefore, the CLASSI modules GLAYER and CLAF were not utilized. The foundation impedances computed by SASSI were provided as input to the CLASSI module SSIN. SSIN solves the equations of motion of the coupled soil/foundation/structure system in the frequency domain, and then calculates the structure's response in the time domain (response acceleration time histories) using an inverse Fourier Transform technique. SSIN computes the response at all the structure's degrees-of-freedom by

simultaneously applying control acceleration time histories in three directions: NS, EW and vertical.

(2) RAI: (a) Impell's version of the computer program CLASSI was reviewed and licensed by the NRC during the SONGS-1 LTS program (References 5 and 12). CLASSI is verified according to Impell's Quality Assurance (QA) program, which, for computer program verification and validation, complies to 10CFR50 Appendix B, ANSI N45.2 and ANSI/ASME NQA-1 standards.

QUESTION III:

Document: Impell Corporation, Calc. No. AUX-01, "Model Development of Auxiliary, Containment, and Internal Building", Rev. 0, Job No. 1390-(?7-1355.

(1) OI: (a) The use of rigid links connecting the centers of mass with the extremities on each floor in formulating the dynamic model is not discussed adequately.

(b) The inclusion of Ad^2 terms in the generation of model beam stiffnesses for shear walls does not appear to be appropriate.

(2) RAI (a) Provide justification for the model development and include a discussion of how the in-house program EDSGAP was used to establish frequency and modal participation.

RESPONSE TO QUESTION III:

(1) OI: (a) When the structures respond in a torsional mode, the outer edges of each floor are subjected to rotational (torsional) accelerations as well as horizontal translational accelerations. Translational accelerations are induced to the outer edges because of their eccentricity to the center-of-mass (CM) of the corresponding floor. In a similar fashion, when structural rocking response occurs, the outer edges of each floor are subjected to rotational (rocking) accelerations as well as vertical translational accelerations. Again, this occurs because the floor edges are eccentric with respect to the floor's CM.

In order to capture both the rotational and translational response at the outer floor edges, massless rigid links are added to the structural models that are connected to the CM and are extended to the four edges of each floor. Thus, the rigid links provide the spatial geometry necessary to model the physical structure. The rigid links are shown in pages 19 to 36 of Calculation No. AUX-01. The rigid links enable the computation of translational response at the outer floor edges, because the response at the outer nodes of the rigid links is directly computed in the SSI analysis. The response spectra generated from the response acceleration time histories of the outer edges of each floor are enveloped

to produce floor response spectra to be used in the design of components that are distant from the CM.

(b) The lateral load carrying system of the Ft. Calhoun Auxiliary and Internal Structures consists of reinforced concrete shear walls. During an earthquake, the inertial loads are resisted by the walls through shear action. Bending deformations of the walls due to the inertial loads are minimal because of the large moments of inertia that the walls possess in their longitudinal direction. The fundamental mass participating modes of the Auxiliary and Internal Structures are shear modes. As an example, Figure III.1 shows the fundamental EW mode shape of the Auxiliary Building for elevations up to +1045 ft. The shear mode is confirmed by the linear shape of the deformation pattern, as opposed to a parabolic shape that bending modes exhibit.

The Ad^2 terms are included only in the flexural (bending) and torsional moments of inertia of each stick model's beam element. Because the fundamental modes of each structure in the horizontal directions are shear modes, the inclusion of the Ad^2 terms does not have any impact on the horizontal translational response of the stick models. In the case of torsional response, the inclusion of the Ad^2 terms is reasonable because the floor slabs have high in-plane stiffness and can adequately transfer the torsional loads to the shear walls.

(2) RAI: (a) Justifications for the model development are provided in OI(a) and (b) above.

The Impell standard program EDSGAP is an enhanced and quality assured (QA) version of the computer program SAP, which is widely used in the industry. EDSGAP has been verified and validated according to Impell's QA program, which complies to 10CFR50 Appendix B, ANSI N45.2 and ANSI/ASME NQA-1 standards. The usage of EDSGAP in seismic structural analysis has been reviewed and approved by the NRC in Southern California Edison's SONGS-1 Long Term Service program (Reference 5). In particular, EDSGAP was used in the seismic analysis of the SONGS-1 Turbine Building (Reference 11).

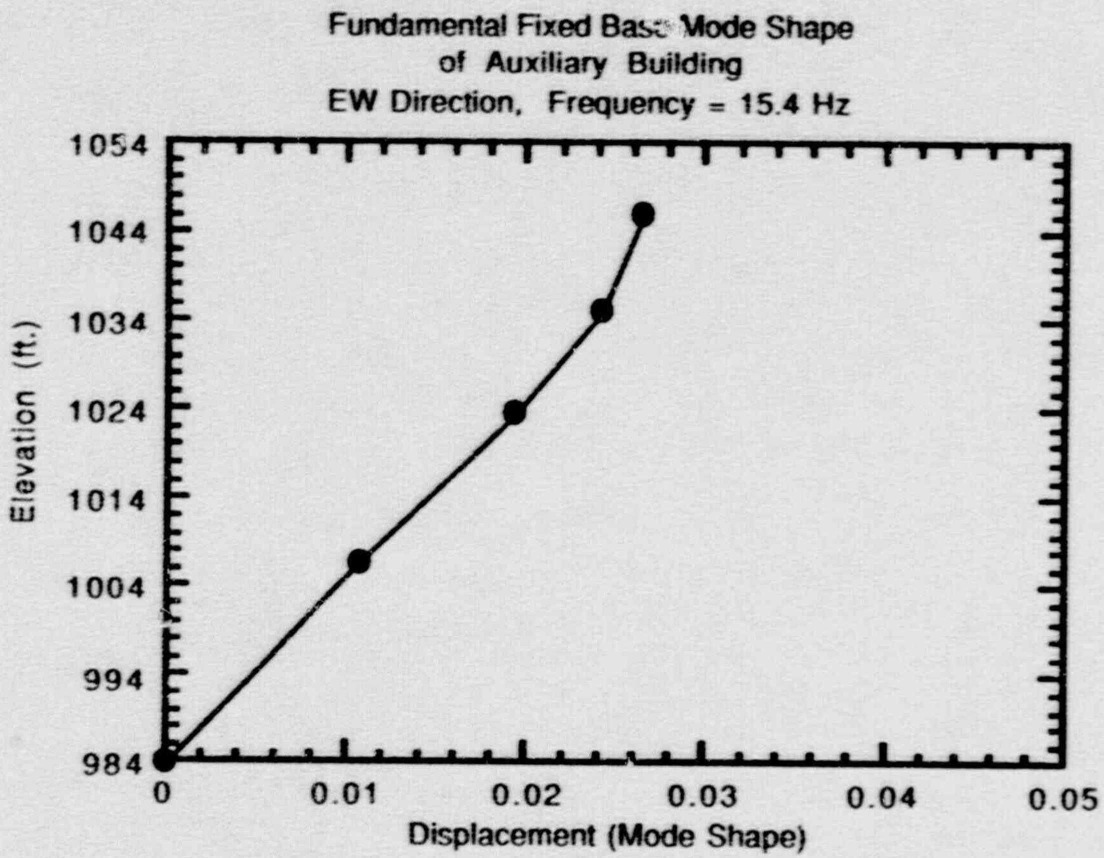


Figure III.1 - Mode Shape of Fundamental Mode Auxiliary Building, EW Direction

QUESTION IV:

Document: Impell Corporation, Calc. No. INT-01, "Intake Structure Model", Rev. 0, Job No. 1390-027-1355.

(1) OI: (a) There is no provision for accidental torsion in the structural model. There is no consideration of deformation relationship between vertical shear walls and floors in formulating the stick model.

(2) RAI (a) Discuss the above OI and provide justification for the model used.

RESPONSE TO QUESTION IV:

(1) OI: (a) Accidental Torsion

The structural model of the Intake Structure does not contain any accidental torsion provisions because it is used only for the purpose of generating in-structure response spectra, and not for design verifying the structure.

Walls and Floors

The lower part of the Intake Structure consists of massive reinforced concrete shear walls spanning the structure in both horizontal directions. The structure's top part consists of a steel frame. More than 90% of the mass participation comes from the shear walls. The fundamental mode of the Intake Structure in each horizontal direction is a shear mode, which is confirmed by the pattern of its mode shape. As shown in Figure IV.1, in the EW direction, the mode shape up to 45 ft. from the basemat is nearly a linear deformation pattern, indicative of shear-type response. Rigid floors do not have any impact on the response of structures that deform in shear, because the floors only provide constraint to bending deformations. Since the bending deformations of the shear walls are negligible, the flexibility of the floors does not affect the structure's horizontal response.

(2) RAI: (a) Discussion for the justification of the model is provided above.

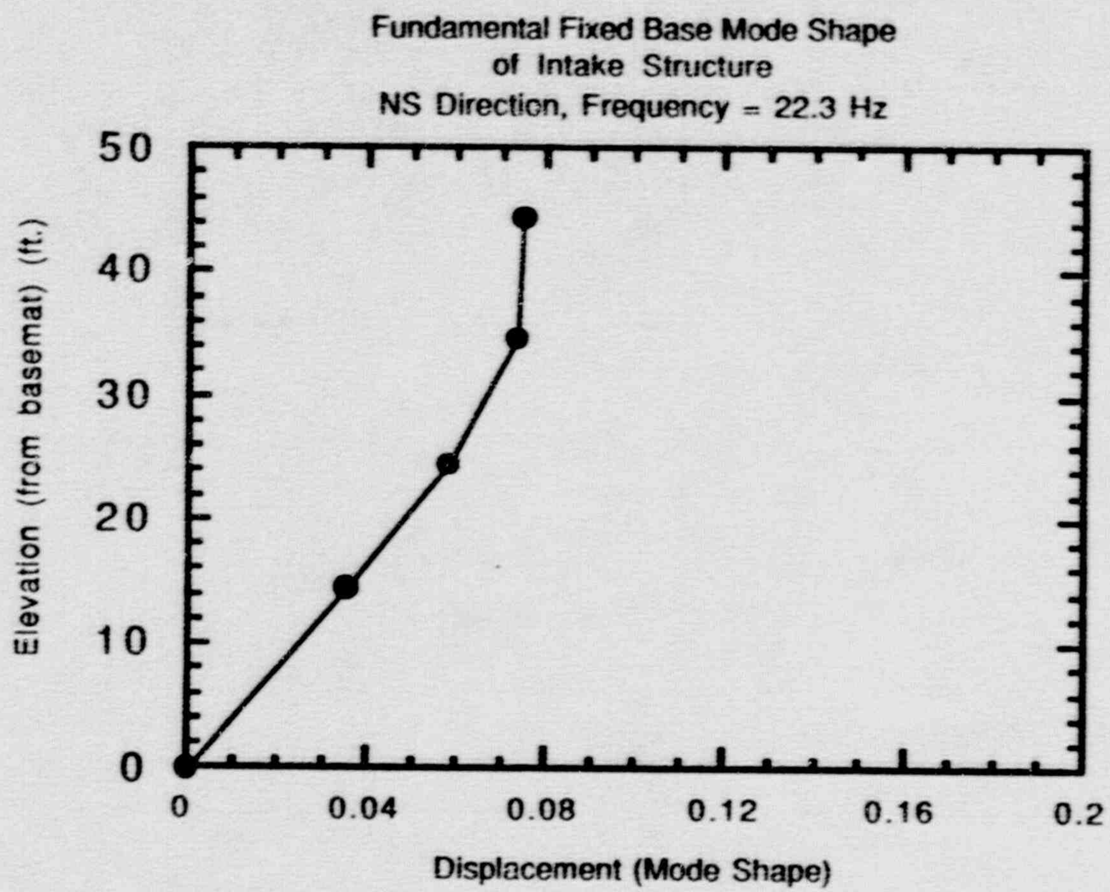


Figure IV.1 - Mode Shape of Fundamental Mode Auxiliary Building, EW Direction

QUESTION V:

Document: Impell Corp.,"SSI Analysis and Design Spectra Generation for Auxiliary, Internal, and Containment Buildings", 9/26/88.

(1) OI: (a) Assumption of rigid mat foundation. Selection of pile foundation impedances.

(b) Impact of piles on ground motion soil column properties for best estimate (BE), upper bound (UB) and lower bound (LB) properties effect of building on soil properties.

(2) RAI (a) Specify the properties of the BE, UB, and LB soil columns. Discuss and provide the necessary justification or verification for the items listed under open issues.

RESPONSE TO QUESTION V:

(1) OI: (a) The foundation geometry of the Reactor Building is shown in Page 11 of Impell Calculation AUX-03 (also shown herein in Figure V.1). The area of the basemat that supports the Containment and the Internal Structure is 10 ft. thick. The remaining part of the basemat, which supports the Auxiliary Building, varies in thickness from 5.5 ft. to 10 ft., as shown in Figure V.2. In addition, as shown in Figure V.3, the Auxiliary Building at basemat elevation has numerous concrete walls which contribute significantly to the out-of-plane stiffness of the basemat. Furthermore, the 803 piles of the Reactor Building contribute to the overall stiffness of the foundation system in the out-of-plane direction of the basemat, because the piles are axially very stiff and are driven into bedrock.

Based on all of the above considerations, it is our judgement that modeling the foundation basemat as rigid is an appropriate representation for the purpose of generating in-structure response spectra.

The computation of pile foundation impedances is documented in Impell Calculation AUX-03. The verification of the methodology used to compute the pile foundation impedances is provided in Impell Calculation V-1. Calculation V-1 describes in detail the extensive

verification program that was conducted in order to incorporate pile foundations in the computer code SASSI.

(b) UB and LB soil properties were not evaluated, only BE properties were calculated. In order to account for variations in soil properties as well as in structural properties, the generated response spectra for all structures were broadened by ±15%. This broadening is consistent with the SRP Revision 1 Section 3.7.2 (Reference 8), and Regulatory Guide 1.122 (Reference 9), which state that, if no special study is performed for parameter variations in soil-structure interaction analysis, the peak width of response spectra should be increased by ±15%.

(2) RAI: (a) Justification for OI (1) and (2) are provided above.

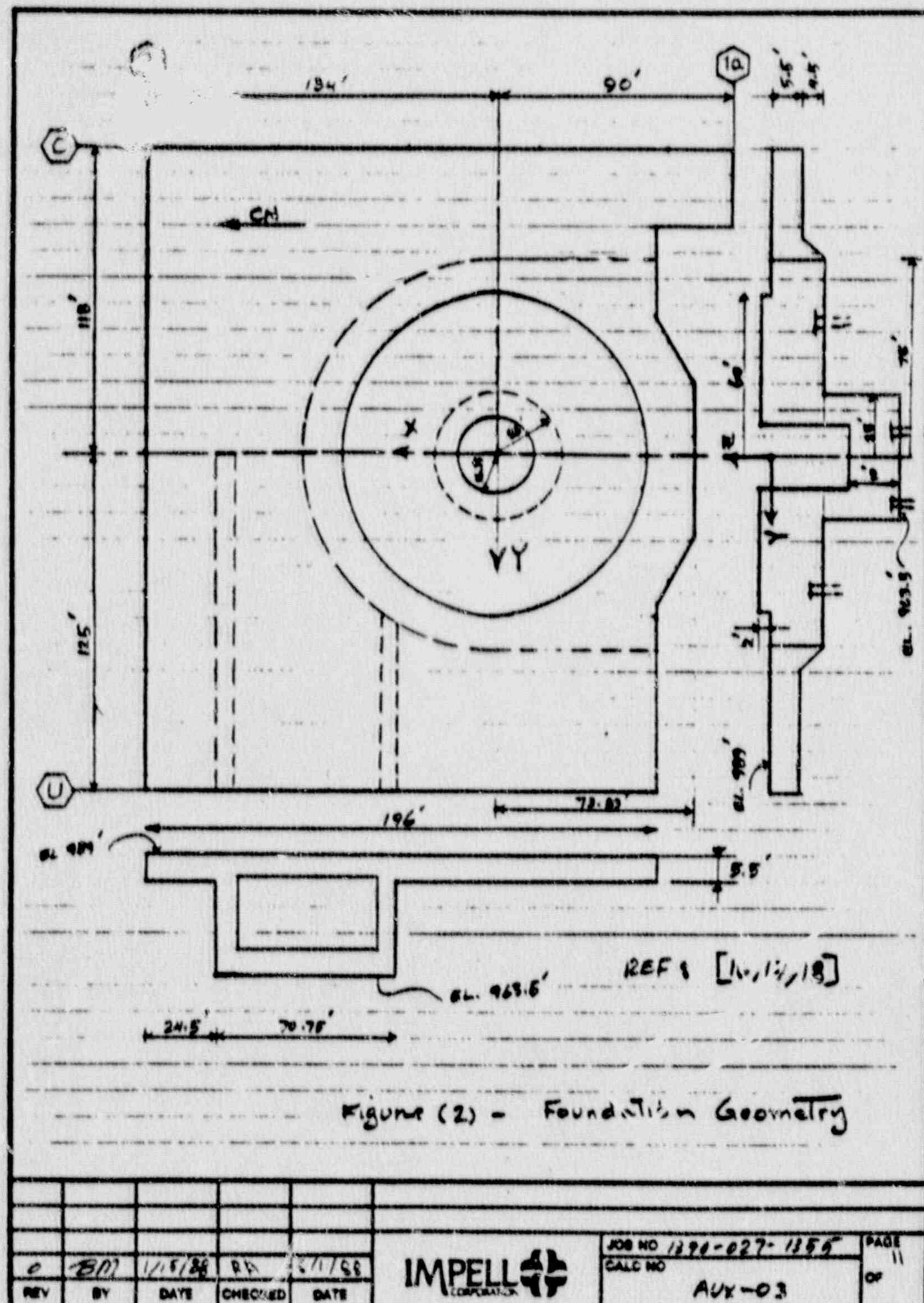


Figure V.1 - Reactor Building Foundat'on Geometry

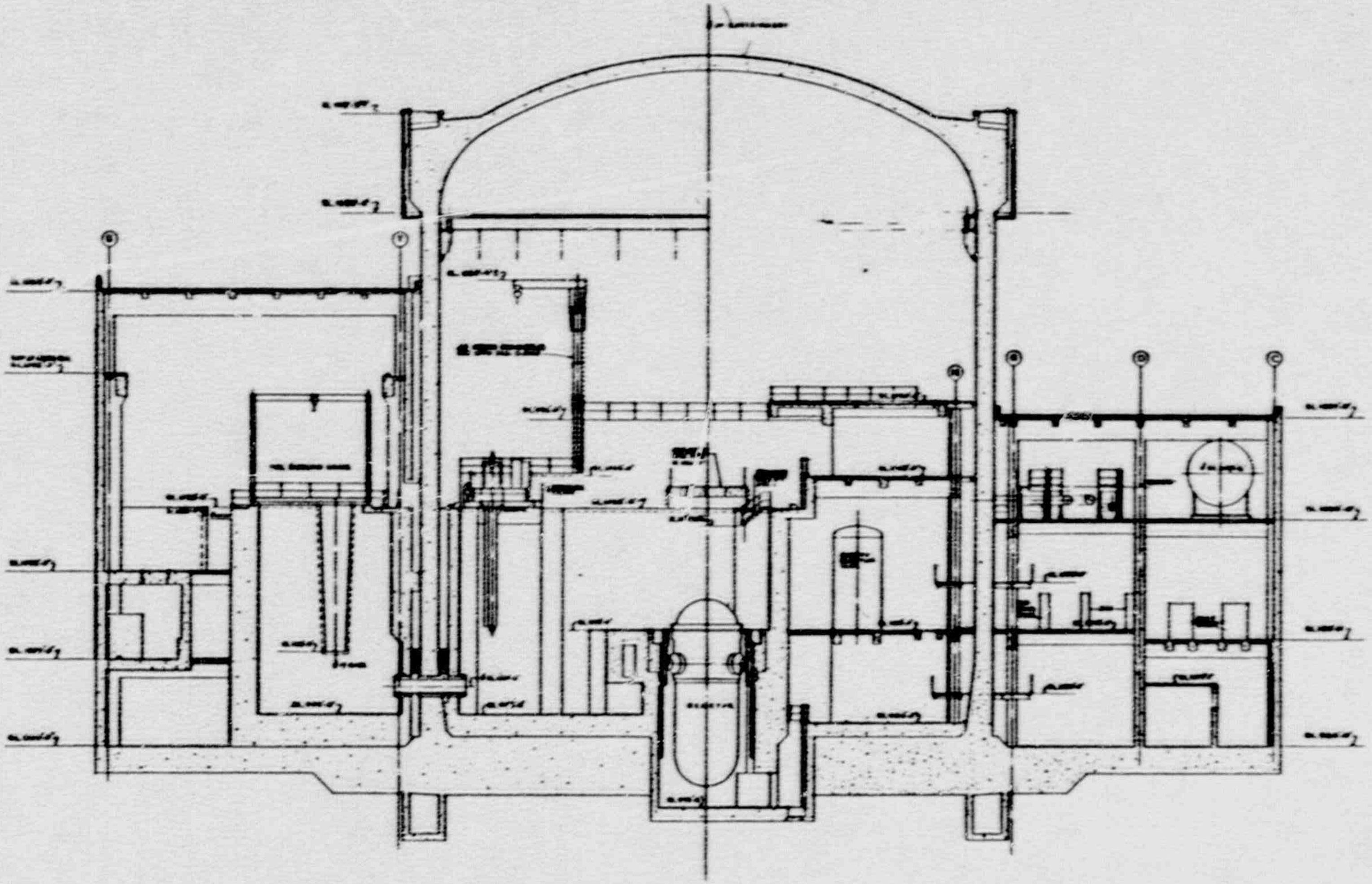


Figure V.2 - Elevation View of Reactor Building

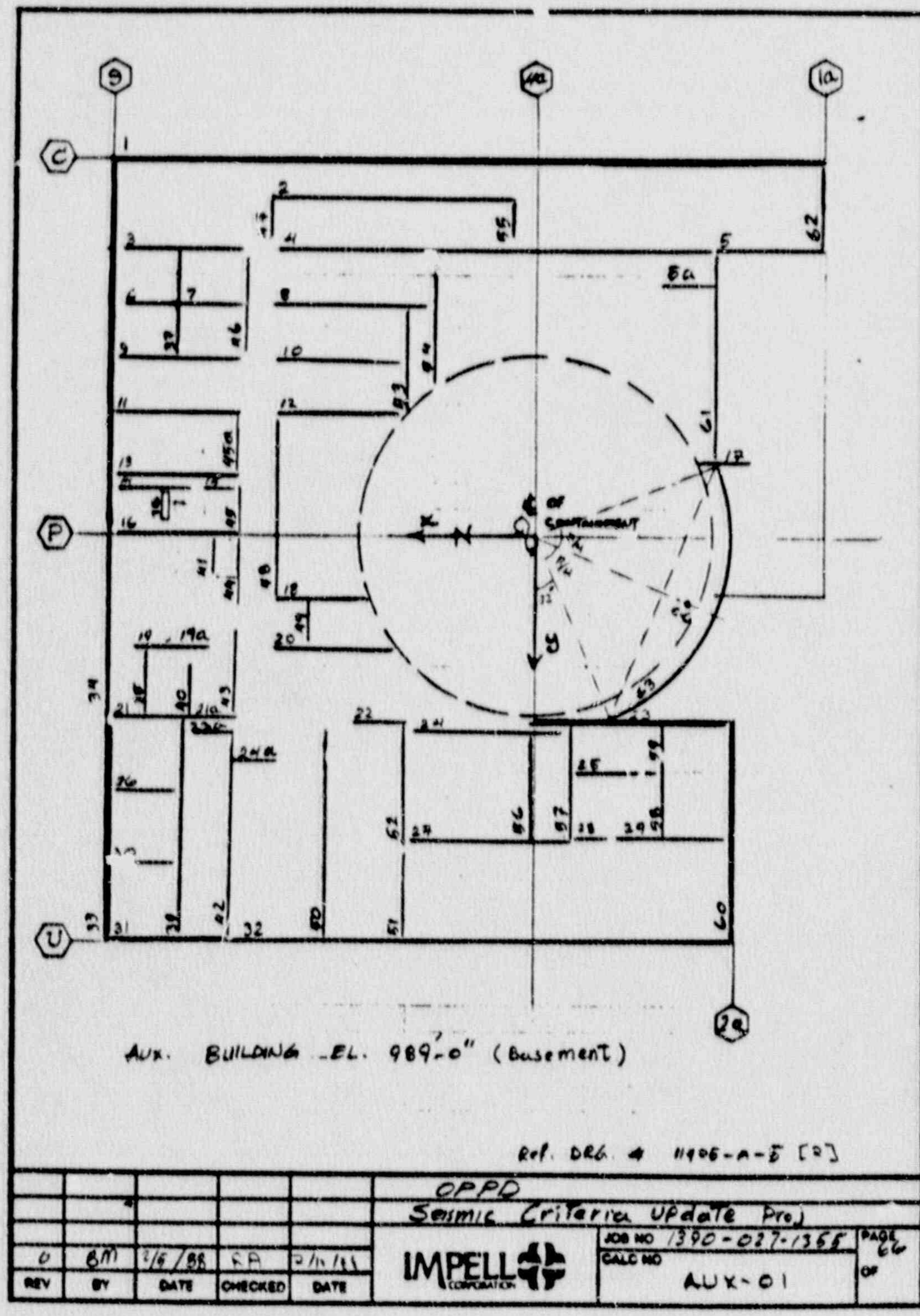


Figure V.3 - Reactor Building Walls at Basemat Level

QUESTION VI:

Document: Impell Corporation, Calc. No. AUX-31, "Design Acceleration Response Spectra for Internal Structure (SSE Fvent)", Rev. 0, Job No. 1390-027-1355.

(2) RAI (a) Supply missing pages 94-103 and 94-105 to 109.

RESPONSE TO QUESTION VI:

(2) RAI: (a) Pages 94 to 103 and 105 to 109 are provided in this package as Attachment 2. These pages show the smoothening of enveloped spectra corresponding to the center of gravity (CG) at elevations +994 ft., +1013 ft., +1038 ft., +1045 ft. and +1056 ft. of the Internal Structure.

QUESTION VII:

Document: Impell Corporation, Calc. No. INT-04, "SSI Analysis for Intake Structure - SSE Event", Rev. 0, Job No. 1390-027-1355.

(1)&(2) OI & RAI:

(a) The Intake Structure consists of reinforced concrete and bolted steel members. The FSAR Appendix F, Table F-2 specifies 2% damping for bolted steel assemblies; it appears that 7% damping was used instead in the CLASSI analysis. Provide justification.

(b) The Intake structure is not embedded on the side facing the Missouri River, its mat is 30 feet below ground surface elsewhere. Provide justification for the use of strain compatible soil properties generated by SHAKE for a soil profile extending from bedrock to ground surface.

(c) Provide justification for not using variations in soil properties.

(d) The information provided does not clearly indicate how the 3-dimensional properties of motion were applied in the calculations. Provide clarifications whether a 3-dimensional simultaneous applications of motion was used or a combination of motions by SRSS to obtain response.

(e) Opting for a solution in the frequency domain and also specifying a cutoff frequency does not appear to be compatible. Provide a justification.

(f) No information is provided on the contact condition between piles and bedrock. Provide information how this was accounted for in the calculations.

(g) Provide information why the potential for sliding and overturning of the Intake Structure as a result of seismic motion was not considered.

(h) Foundation impedances were calculated for 22 frequencies. In order to capture the entire response spectrum, including peak responses, the structural response calculations should include responses at the natural frequencies of the structure. Discuss the above in the light of the results obtained from the structural response calculations.

RESPONSE TO QUESTION VII:

(1)&(2) OI & RAI

(a) Critical damping ratios used in the analytical model of the Intake Structure for all structural members were obtained from Regulatory Guide 1.61 (Reference 10). According to Table 1 of Regulatory Guide 1.61, for an SSE event, damping for bolted steel structures and reinforced concrete structures is 7% of critical.

Because the Intake Structure consists of reinforced concrete walls (in the lower part) and bolted steel members (in the upper part), modal damping for all modes in CLASSI was specified as 7%.

(b) The soil profile used in the SSI analysis of the Intake Structure consists of:

(i) The bedrock (as a halfspace below elevation +934 ft.), and,

(ii) Soil layers between elevation +934 ft. and +974 ft. (bottom of Intake Structure basemat).

The properties of the soil layers between +934 ft. and +974 ft. are identical to the properties of the layers between +934 ft. and +974 ft. obtained from the SHAKE analysis. The soil profiles used in the SHAKE and the SASSI/CLASSI analyses are shown in the schematic of Figure VII.1.

(c) Similar to the response provided for Question V, OI(b), the generated response spectra at the Intake Structure were broadened by ±15%. The ±15% broadening is consistent with the recommendations of SRP Revision 1 Section 3.7.2 (Reference 8), and Regulatory Guide 1.122 (Reference 9) for broadening spectra in the absence of parameter variation studies.

(d) The control acceleration time histories in the SASSI/CLASSI analysis of the Intake Structure were applied simultaneously in three directions: NS, EW and vertical. The control acceleration time histories are statistically independent with correlation coefficient less than ±0.16.

(e) The foundation impedances for the Intake Structure are generated at 22 discrete frequencies. These frequencies are

documented in Calculation INT-04. Because CLASSI operates in the frequency domain, the foundation impedances are calculated for a user specified representative number of frequencies and are subsequently interpolated at 4096 frequency points in the range of the frequencies considered in the analysis (0.5 to 30.9 Hz). It has been shown that this method provides accurate SSI results (Reference 7) and has been reviewed by the NRC in the LTS program of SONGS-1 (References 5 and 12).

The fundamental horizontal frequencies of the Intake Structure are 22.3 and 30.8 Hz. These modes account for 98% of the mass participation in each horizontal direction. Impedances were explicitly calculated at 22.3 and 30.9 Hz, in order to provide exact impedance values at the fundamental frequencies of the Intake Structure. The fundamental frequency of the Intake Structure in the vertical direction is at 47.6 Hz, which is well into the rigid range.

(f) The piles are driven approximately 5 ft. into bedrock, as documented in the USAR, Section 2.0 Appendix C (Reference 2). This condition is reflected in the SSI modeling with the program SASSI. At the pile cap, the piles are constrained by the basemat in six degrees-of-freedom (three translational and three rotational). Therefore, the top of each pile is constrained to move together with the basemat in all directions. The tip of each pile is located 5 ft. into the bedrock. The tip of the pile interacts with the bedrock in three translational degrees-of-freedom. The rotational degrees-of-frredom at the tip are free.

(g) For the generation of upgraded in-structure response spectra, it is not necessary to design verify the Ft. Calhoun structures. Therefore, design verification calculations for sliding and overturning were not performed as part of the spectra development work.

(h) Refer to OI(e) for the justification of the foundation impedances and the frequencies used in the analysis.

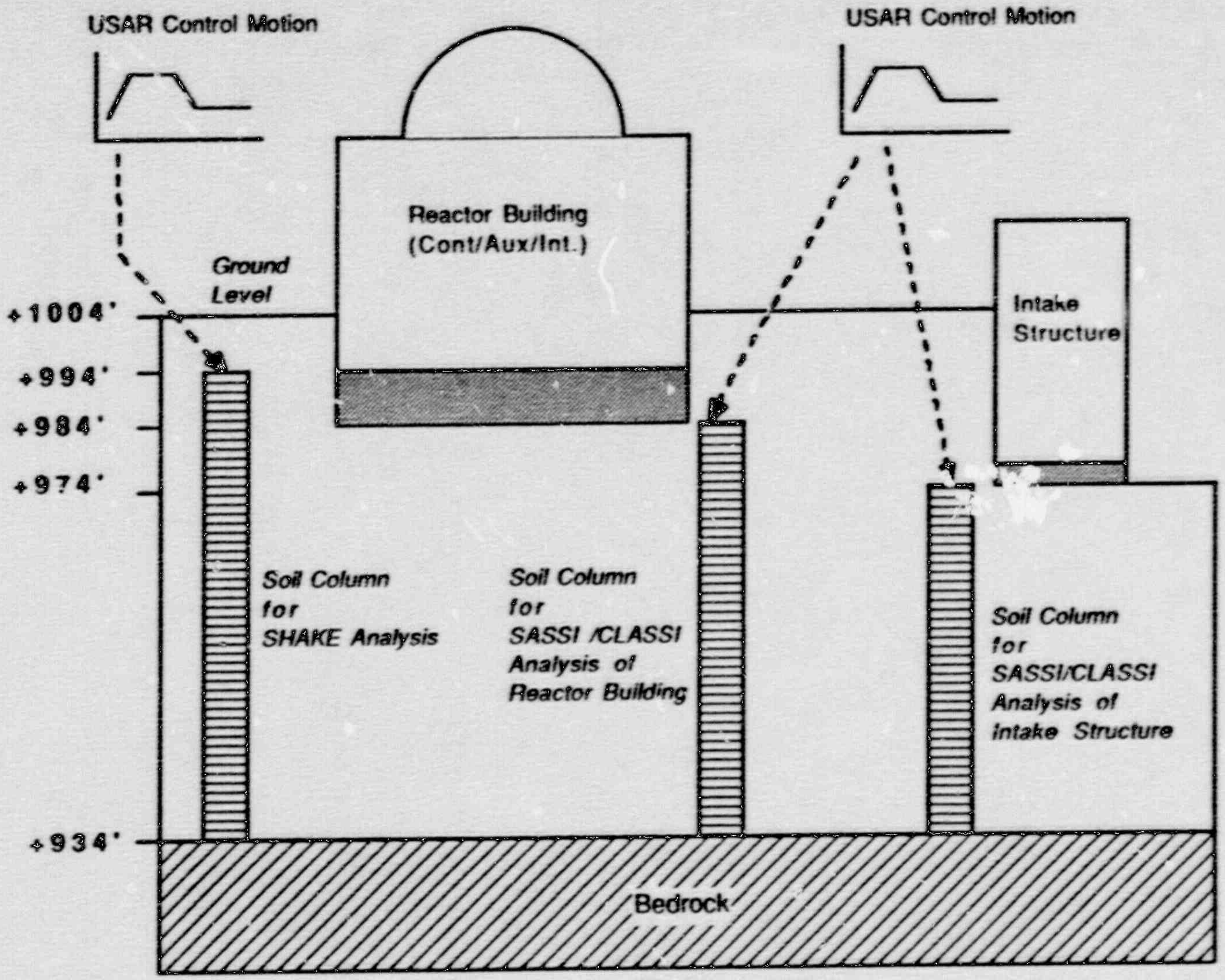


Figure VII.1 - Schematic of the Soil Profiles Used in the Seismic Analyses

QUESTION VIII:

Document: Impell Corporation, Calc. No. AUX-04, "SSI Analysis for Auxiliary/Containment/Internal Structures (OBE Event)", Rev. 0, Job No. 1390-027-1355.

(2) RAI (a) Provide the analytical basis for the "Direct floor response spectra generation" method employed in the Ft. Calhoun OBE analysis.

RESPONSE TO QUESTION VIII:

(2) RAI: (a) Impell Calculation RAN-01 and excerpts from the theoretical background of the Impell standard program SPECGEN are provided in this package as Attachments 4 and 5, in order to provide additional information on the analytic basis of the direct floor response spectra generation. Calculation RAN-01 documents the verification of the SASSI module RANDOM, which was used in the direct generation of the Fort Calhoun OBE spectra. The theoretical basis of the direct generation method is described in detail in Theoretical Background Section of the Verification File of the Impell computer program SPECGEN (Reference 14).

QUESTION IX:

Document: Impell Corporation, Calc. No. INT-05, "SSI Analysis for Intake Structure, OBE Event", Rev. 0, Job No. 1390-027-1355.

(1) OI:

(a) The SRP recommends that the input motion be applied at the top of competent material (elev. 934) or at an outcrop.

(b) The natural frequencies of the Intake Structure should be included in the foundation impedance calculation and subsequent SSI calculations.

(c) Upper and lower bound soil properties should be included in the SHAKE calculations.

(2) RAI

(a) Provide Impell's versions of SHAKE theoretical basis and user's manual.

(b) Provide Impell's version of RANDOM theoretical basis and user's manual.

(c) Provide analyses which include a, b, and c conditions discussed under OI.

RESPONSE TO QUESTION IX:

(1) OI:

(a) The seismic control motion is applied in the free field at elevation +974 ft., which corresponds to the level of the foundation basemat of the Intake Structure (refer to the schematic of Figure VII.1). This is conforming to SRP Revision 1 Section 3.7.1.I.4 recommendations, which were available during the duration of the alternate spectra development work.

(b) Refer to Question VII, OI(e) for justification on the foundation impedances and the frequencies used in the analysis.

(c) Similar to the response provided for Question V, OI(b), the generated response spectra at the Intake Structure were broadened by ±15%. The ±15% broadening is consistent with the recommendations of SRP Revision 1 Section 3.7.2 (Reference 8), and Regulatory Guide 1.122 (Reference 9) for broadening spectra in the absence of parameter variation studies.

(2) RAI: (a) The User's Manual of Impell's version of the program SHAKE is included in this package as Attachment 6. The source code of the program is included in the User's Manual.

(b) The User's Manual and the theoretical basis of the SASSI module RANDOM are provided in this package as Attachments 4 and 5.

(c) Justification for OI (a), (b) and (c) is provided above.

QUESTION X:

Document: Impell Corporation, Calc. No. SOIL-1, "Development of Soil Properties for SSI Analysis", Rev. 0, Job No. 1390-027-1355.

(1) OI:

(a) Soil profile at the Ft. Calhoun site includes a few layers of very soft to moderately soft sands to a depth of approximately 60 feet overlying competent material. Applying the ground motion at the top of these soft layers produce unacceptable de-amplification.

(b) Strain-dependent shear moduli and damping degradation data provided by Seed for sand type materials were employed in the SHAKE analysis. A study to verify that the materials at the site correlate with those used for the data generated by Seed was not performed.

(c) The USAR states that the use of piles to support the structures at the Fort Calhoun site were a direct consequence of the liquefaction potential at the site. The present analysis does not appear to address this condition.

(d) The SRP recommends that variations in soil properties be included in the SSI analysis, i.e., upperbound and lower bound soil properties as well as a median soil property.

(e) The selected value of 3140 fps for the shear wave velocity in limestone does not appear to be corroborated by test data.

(f) The effect of building containment to GMAX was not discussed.

(g) Damping results are not discussed.

(2) RAI

(a) Provide a justification for the apparent discrepancies listed under the OI. In particular, justify the use of SSI under soil liquefaction conditions.

RESPONSE TO QUESTION X:

(1) OI: (a) The soil column SHAKE model developed to determine strain-compatible soil properties (shear modulus and damping) contains soil layers from elevation +994 ft. to elevation +934 ft. (top of bedrock). The control motion in the SHAKE free-field soil analysis was applied at the level of the foundation basemat. This is consistent with SRP, Rev. 1, Section 3.7.2 recommendations (Reference 8). The SSI control motion in the SASSI/CLASSI analysis is identical to the control motion used in the SHAKE analysis. Therefore, the control motion used in the SASSI/CLASSI analysis was not a deamplified control motion.

(b) As documented in Impell Calculation No. SOIL-1, the average Seed and Idriss curve from Reference 6 was used as the soil damping ratio variation with strain. This curve was employed as a representative variation of the sand material in the Fort Calhoun site to be used in the SHAKE analysis. The selection was based on the following considerations:

Geotechnical investigations performed at the Fort Calhoun site as part of the preliminary design of Ft. Calhoun Unit 2 (Reference 7; also included in Calc. No. SOIL-1) show that soil damping ratios from resonant column test data and cyclic triaxial test data are contained in the area shown between the dotted lines in Figure X.1. The average Seed and Idriss curve is nearly identical to the upper bound of these test data. Since energy dissipation due to frictional forces between the piles and the soil, and between the basemat and the soil are not accounted for in the SSI model, using the upper bound soil damping data are, by engineering judgement, more appropriate to represent realistic energy dissipation conditions at Ft. Calhoun during a seismic event. Furthermore, the use of the Seed and Idriss damping curve has been shown to give excellent results in experiment vs. analysis correlation studies of soil response of similar sites to Fort Calhoun (refer to the discussion in item (g) below). Therefore, the use of the Seed and Idriss average damping curve is adequately justified for the computation of strain-compatible soil properties.

(c) Soil liquefaction is a geotechnical design consideration involved in the original site evaluation of the Ft. Calhoun Unit 1 plant. As such, it is addressed in the Ft. Calhoun Unit 1 USAR (Reference 2), Section 2.0, Appendix C. The SSI analyses were performed under the assumption that

the soil will not liquefy during a postulated Safe Shutdown Earthquake.

(d) In order to account for variations in soil properties as well as in structural properties, the generated response spectra at all structures were broadened by ±15%. The ±15% broadening is consistent with the SRP Revision 1 Section 3.7.2 (Reference 8), and Regulatory Guide 1.122 (Reference 9), which state that, if no special study is performed for parameter variations in soil-structure interaction analysis, the peak width of response spectra should be increased by ±15%.

(e) The selected value of 3140 ft/sec for the shear wave velocity in limestone is representative of the average value of all rock material below elevation +934 ft., and is derived from the geophysical data shown in Figure 4.2 of Impell Calculation SOIL-1. To demonstrate that a higher shear wave velocity value selected for the rock material does not have any impact on the results, an additional SHAKE analysis was performed. In this analysis the shear wave velocity of the rock is arbitrarily increased to 6000 ft/sec, and the soil response at selected depths is compared to the original analysis results. The analysis results show that the free-field soil response spectra with 3140 ft/sec rock and with 6000 ft/sec rock are identical at all depths. Therefore, the shear wave velocity of rock has no impact on the results.

(f) The vertical gravity loads of the Reactor Building are directly transferred to the bedrock through the piles. The overburden pressure caused by the weight of the Reactor Building is supported by the bedrock. Therefore, there is no effect on the soil shear modulus caused by the weight of the Reactor Building.

(g) The strain-compatible soil damping ratios calculated by SHAKE and used in the SSE analyses are tabulated in Table 5.1 of Impell Calculation No. SOIL-1. The damping ratios vary from 3.7% in the upper layers to 8.9% in the bottom layer, which directly overlies rock. The computed damping ratios are reasonable and consistent with experimentally measured damping ratios for soft soil sites subjected to earthquake motions of magnitude similar to the Fort Calhoun motions used in the SSI analyses.

The reasonableness of the damping ratios is adequately demonstrated by the comparison between the experimentally measured and analytically calculated soil response at the Lotung site. The Large-Scale Seismic

Experiment at Lotung, Taiwan, sponsored by EPRI/NRC/TPC (Reference 7), provided the means to assess the accuracy of analytical tools to predict SSI response. As an industry investigator, Impell participated in this program and evaluated the SSI response of the model containment structure using SASSI. In addition, Impell calculated the free-field soil response using both SASSI and SHAKE.

The Lotung site is a soft soil site with sand material of shear wave velocities very similar to the Fort Calhoun soils. The laboratory tests result in soil material damping ratios in the range of the Fort Calhoun material damping ratios (Figure X.2, from Reference 7). In the Lotung SSI analyses, Impell utilized the damping curve shown in Figure X.2, which is very similar to the Seed and Idriss average damping curve. The strain-compatible damping ratios used by Impell in the SSI analysis of the May 20, 1986 and November 14, 1986 earthquakes are tabulated in Table X.1 (Reference 7). The horizontal peak ground accelerations (PGA) of the two Lotung earthquakes were 0.17g and 0.20 g, respectively, which are similar to the Ft. Calhoun PGA. The damping values used in the Lotung analysis are tabulated in Table X.1 (from Reference 7). The results of the correlation study between experimentally measured and analytically calculated seismic response show a nearly perfect match of the free-field motion at depth between analysis and experiment. Figure X.3 shows the response of the free-field soil (in the form of response spectra) at a depth of 6 meters (20 ft.) and 47 meters (154 ft.), respectively. These comparisons demonstrate the appropriateness of the use of soil material damping curves similar to the average Seed and Idriss curve for soft soil sites.

(2) RAI: (a) Justifications for the issues listed under the OI are provided above. Soil liquefaction is discussed in OI (c).

Table X.1 - Soil Profile Properties Used in Lotung Analysis (Impell Data)

Layer No.	Thickness (m)	Bulk Density (gm/cm^3)	Shear Modulus (kN/cm^2)	Shear Wave Velocity (m/sec)	Compressional Wave Velocity (m/sec)	Poisson's Ratio	Material Damping (%)
1	1.50	1.85	1.33	84	352.8	0.47	7.4
2	1.50	1.97	1.77	94	394.8	0.47	8.2
3	1.57	2.08	2.16	101	424.2	0.47	9.1
4	1.69	1.77	2.77	124	520.8	0.47	9.9
5	1.49	1.81	3.21	132	554.4	0.47	10.0
6	1.75	1.85	3.70	140	588.0	0.47	10.1
7	1.66	1.86	4.10	147	617.4	0.47	10.8
8	1.34	1.86	4.10	147	617.4	0.47	10.8
9	2.25	1.86	4.38	152	638.4	0.47	11.2
10	2.56	1.99	4.81	154	646.8	0.47	11.1
11	1.69	2.11	5.30	157	659.4	0.47	11.0
12	2.50	1.89	7.63	199	835.8	0.47	10.0
13	2.50	1.88	8.05	205	861.0	0.47	9.9
14	3.00	1.86	8.44	211	886.2	0.47	9.8
15	3.00	1.91	6.95	189	793.8	0.47	10.8
16	3.50	1.89	7.18	193	810.6	0.47	10.2
17	3.50	1.86	7.36	197	827.4	0.47	9.6
18	3.00	1.76	7.47	204	856.8	0.47	8.0
19	3.50	1.79	7.89	208	873.6	0.47	8.7
20	2.50	1.81	8.29	212	890.4	0.47	8.5
21	4.00	1.69	9.19	231	970.2	0.47	8.6
22	4.50	1.69	9.43	234	982.8	0.47	8.5
23	4.50	1.70	9.32	238	999.6	0.47	8.4
Halfspace	--	1.70	27.73	400	1680.0	0.47	4.0

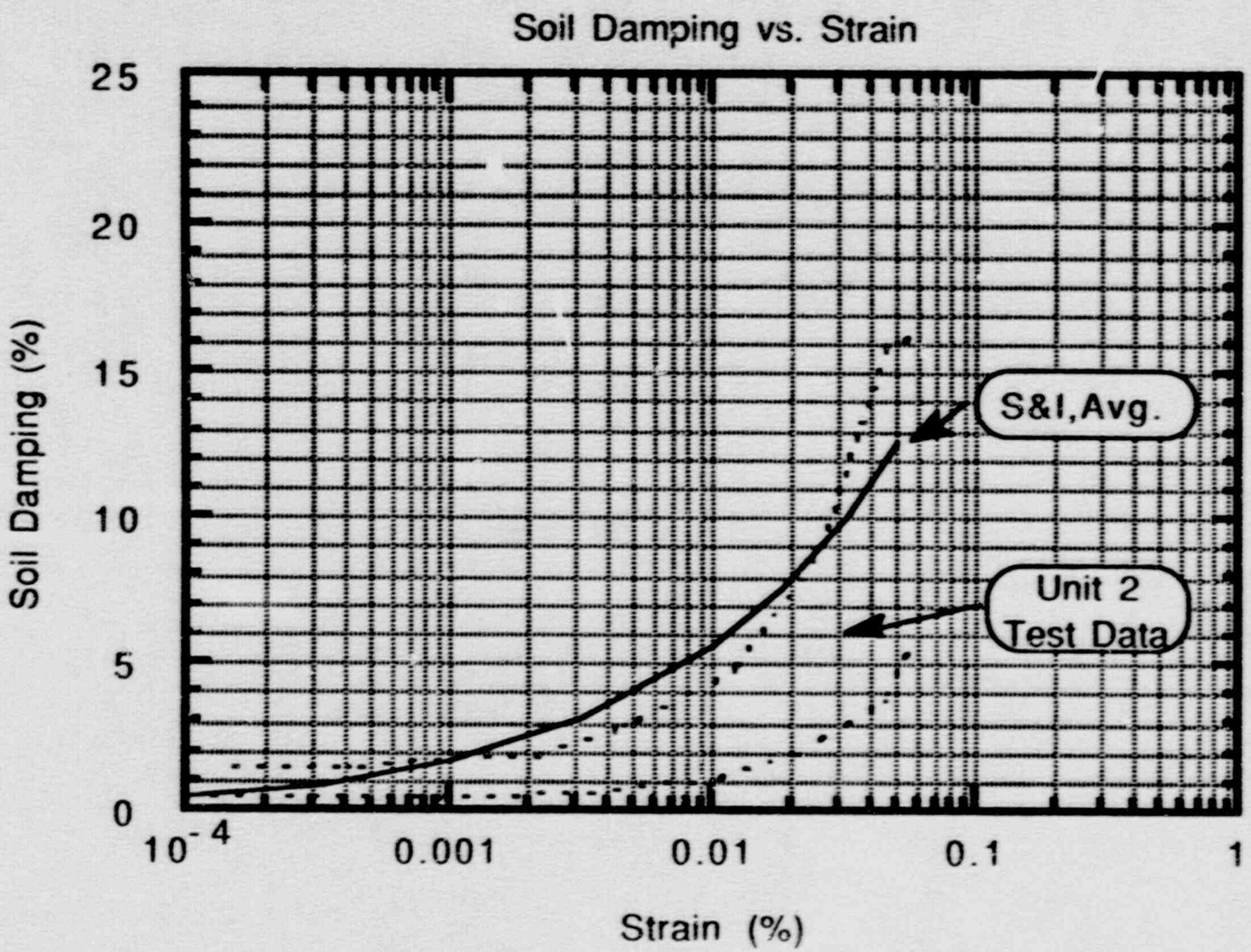
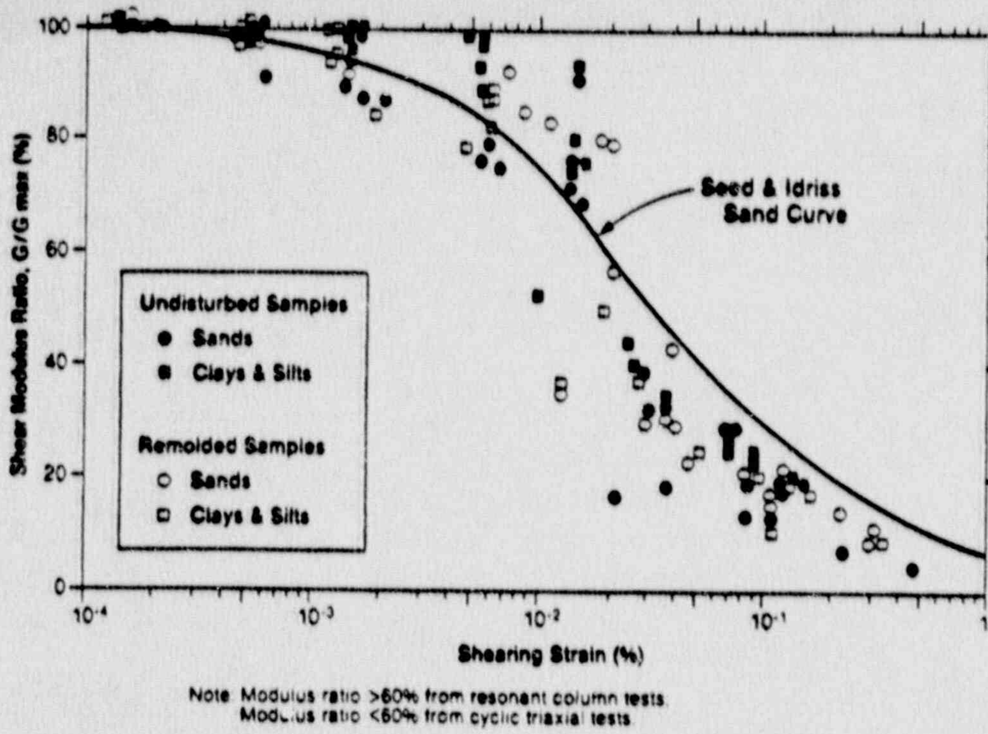
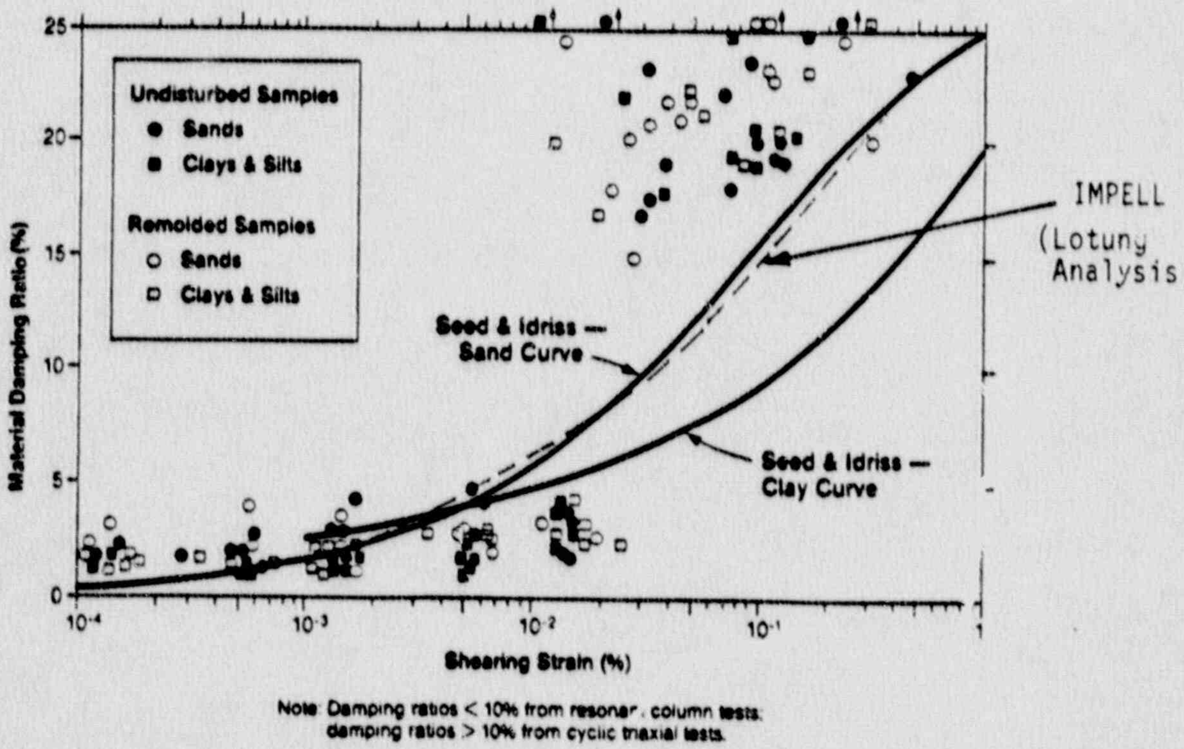


Figure X.1 - Variation of Soil Damping with Strain
(Fort Calhoun Data)



SHEAR MODULUS RATIO DATA FOR LOTUNG SITE



DAMPING RATIC DATA FOR LOTUNG SITE

Figure X.2 - Variation of Soil Damping with Strain
(Lotung Data)

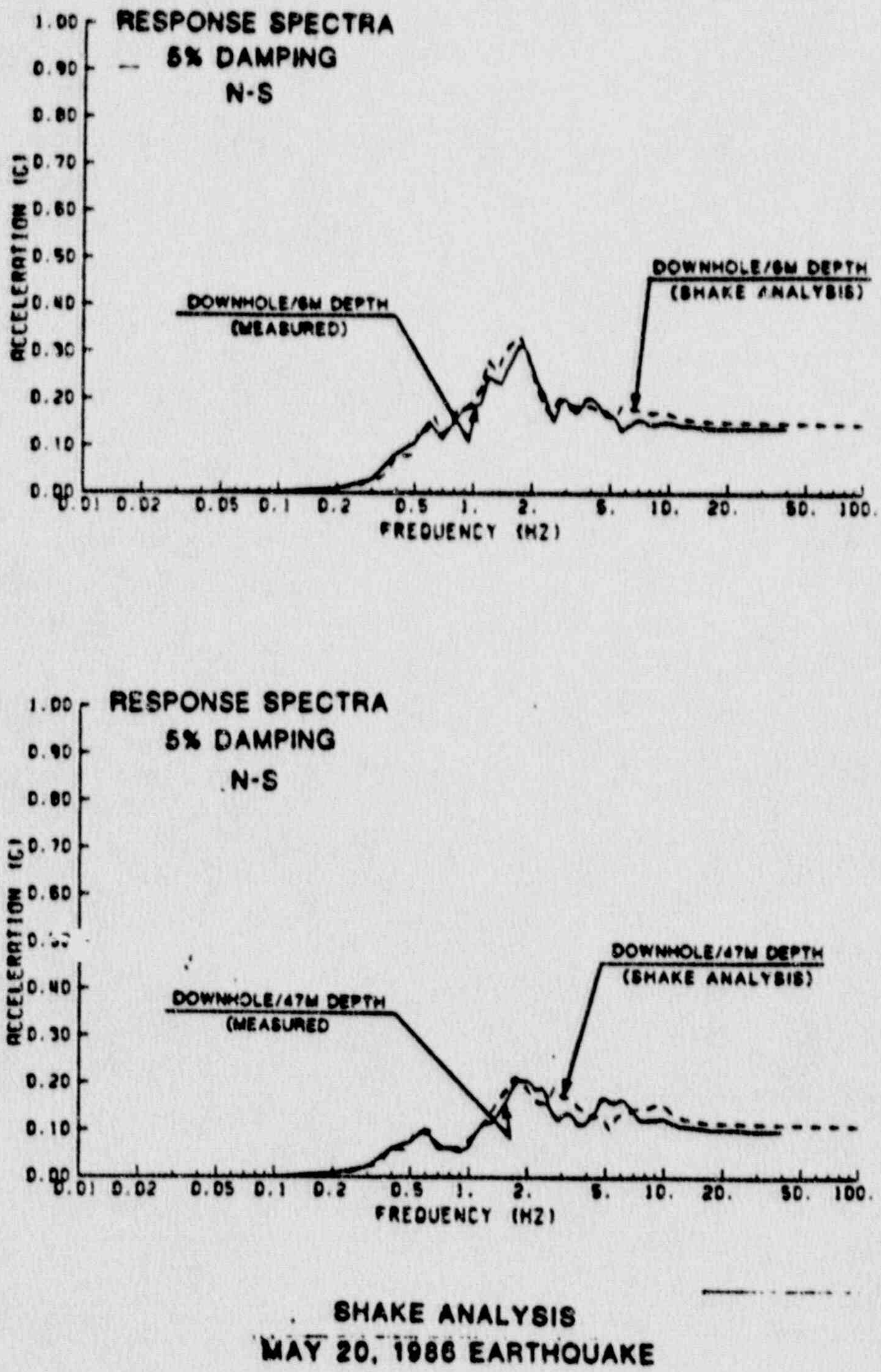


Figure X.3 - Comparison of Analytical vs. Measured Soil Response (Lotung Analysis, SHAKE Program)

QUESTION XI:

Document: Impell Corporation, Calc. No. AUX-05, "Seismic Anchor Movements (SAM) for Auxiliary, Internal, and Containment Buildings", Rev. 0, Job No. 1390-027 1355.

(2) RAI (a) Provide the Impell Calc. TURB-02 "Design Spectra and SAM for Turbine Bldg. for SSE Event", Rev. 0.

RESPONSE TO QUESTION XI:

(2) RAI: (a) Impell's Calculation No. TURB-02, Rev. 0 is included in this package as Attachment 3.

SECTION 3: REFERENCES

1. NRC's Questions to OPPD on the Generation of the Refined Seismic Spectra at FCS, telecopied to Tom Therkildsen (OPPD) from Anthony Bournia (NRC), August 1990.

2. Docket No. 50285, Fort Calhoun Updated Safety Analysis Report (USAR), Revision 7/87.

3. OPPD Report entitled "Generation of In-Structure Response Spectra for Fort Calhoun Unit 1", Volumes I, II and III, February, 1989.

4. Impell Corporation, Calculation No. THG-1, "Generation of Artificial Time Histories", Rev. 0, Job No. 1390-027-1355, Computer Runs with Program SIMQKE No. THG-1-1B and THG-1-1C.

5. U.S. NRC, Docket No. 50-206, "Safety Evaluation by the Office of Nuclear Reactor Regulation Relating to the Long-Term Service Seismic Reevaluation Program, Southern California Edison Company, San Diego Gas and Electric Company, San Onofre Nuclear Generating Station, Unit No. 1", July 11, 1986.

6. Seed, H. Bolton, and Idriss, I.M., "Soil Moduli and Damping Factors for Dynamic Response Analyses", Report No. EERC 70-10, Earthquake Engineering Research Center, University of California, Berkeley, California, 1970.

7. Electric Power Research Institute, Report No. EPRI NP-6154, Volumes 1 and 2, "Proceedings: EPRI/NRC/TPC Workshop on Seismic Soil-Structure Interaction Analysis Techniques Using Data From Lotung, Taiwan", March, 1989.

8. U.S. Nuclear Regulatory Commission, NUREG-0800, Standard Review Plan, Revision 1, July, 1981.

9. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.122, "Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components", Revision 1, February, 1978.

10. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants", October, 1973.

11. Impell Report No. 01-0310-1430 to Southern California Edison Company, "Generation of Floor Response Spectra for the Reactor and Turbine Buildings, SONGS-1 LTS Seismic Reevaluation Program," Revision 0, March 1986. Submitted to the NRC by letter from M.O. Medford to G.E. Lear, dated May 28, 1986.

12. SONGS-1 Seismic Program For Long Term Service, Responses to Action Items Resulting from the 2/12/85 and 2/27/85 Meetings with the NRC, Southern California Edison Company, March 11, 1985.

13. Shinozuka, M., Mochio, T., and Samaras, E.F., "Power Spectral Density Functions Compatible with NRC Regulatory Guide 1.60 Response Spectra", U.S. Nuclear Regulatory Commission Report No. NUREG/CR-3509, June, 1988.

14. ABB Impell Corporation, Standard Computer Program SPECGEN,"A Computer Program to Perform Damping Extrapolation of Acceleration Response Spectra", Verification File, Version August 1988, Revision 0.

ATTACHMENT 1
COMPUTER PROGRAM SIMQKE
USER'S MANUAL

SIMQKE: A PROGRAM FOR ARTIFICIAL MOTION GENERATION

USER'S MANUAL

and

DOCUMENTATION

November 1976

Department of Civil Engineering

Massachusetts Institute of Technology

SIMQKE: A PROGRAM FOR ARTIFICIAL MOTION GENERATION

The program SIMQKE has these major capabilities: it computes a power spectral density function from a specified smooth response spectrum; it generates statistically independent artificial acceleration time histories and tries, by iteration, to match the specified response spectrum. It also performs a baseline correction on the generated motion to ensure zero final ground velocity and, of course, it calculates response spectra with the time histories as input.

The object herein is to describe briefly the algorithms used in the first two capabilities. An explanation of the input to SIMQKE and complete flowchart (Fig. 1) are given; furthermore, an example and program listing are appended.

BRIEF DESCRIPTION OF THE MOTION GENERATION PROCEDURE

The method used by the program for artificial motion generation is based on the fact that any periodic function can be expanded into a series of sinusoidal waves:

$$X(t) = \sum_n A_n \sin(\omega_n t + \phi_n) \qquad (1)$$

A_n is the amplitude and ϕ_n is the phase angle of the n^{th} contributing sinusoid. By fixing an array of amplitudes and generating different arrays of phase angles, one obtains different motions with the same general appearance but different details. The computer uses a random number generator to produce strings of phase angles with uniform likelihood in the range between 0 and 2π.

The amplitudes A_n are related to the (one-sided) spectral density function $G(\omega)$ in the following way:

$$G(\omega_n)\Delta\omega = \frac{A_n^2}{2} \qquad (2)$$

Since the total power may be expressed as:

$$\sum \frac{A_n^2}{2} = \sum G(\omega_n)\Delta\omega \rightarrow \int_0^\infty G(\omega)d\omega \qquad (3)$$

$G(\omega_n)\Delta\omega$ may be interpreted as the contribution to the total power of the motion from the sinusoid with frequency ω_n. Allowing the number of sinusoids in the motion to become very large, the total power will become the area under the continuous curve $G(\omega)$.

The power of the motion produced by using Eq. 1 does not vary with time. To simulate the transient character of real earthquakes, the steady-state motions are multiplied by a deterministic envelope function $I(t)$. The artificial motion $Z(t)$ then becomes:

$$Z(t) = I(t) \sum_n A_n \sin(\omega_n t + \phi_n) \qquad (4)$$

The resulting motion is stationary in frequency content with a peak acceleration close to the target peak acceleration. In this program, we have incorporated three different intensity envelope functions such as "Trapezoidal" (Hou, 1968), "Exponential" (Liu, 1969), and "Compound" (Jennings, 1968) functions as shown in Fig. 2. The program artificially raises or lowers the generated peak acceleration to match exactly the target peak acceleration. The response spectra corresponding to the motion (4) are then computed. The response spectrum for one chosen damping value is called the "target" response spectrum which the program will attempt to "match."

To smoothen the calculated spectrum and to improve the matching, an iterative procedure is implemented. In each cycle of the iteration, the calculated response is compared with the target at a set of control frequencies (the user specifies the number of control frequencies). The ratio of the desired response to the computed response is obtained at each control frequency and the corresponding value of the power spectral density is modified in proportion to the square of this ratio, i.e., at any cycle i:

$$G(\omega)_{i+1} = G(\omega)_i \left[\frac{S_v^{(\omega)}}{S_{v(\omega)}^{(i)}} \right]^2 \qquad (5)$$

where S_v is the target spectral value. With the modified spectral density function a new motion is generated and a new response spectrum is calculated. The procedure should not be expected to be convergent at all control frequencies; the response at a control frequency is dependent not only on the spectral density function value for that frequency, but also on other values at frequencies close to the frequency of interest as well. Usually, it is not productive to iterate for more than about 4 cycles. If an adequate level of agreement cannot be reached, the user is advised to "start fresh" by generating an entirely new motion (with a new set of random phase angles). For more elaborate explanation of some features of the program, the reader is referred to Gasparini and Vanmarcke (1976).*

* Gasparini, D. and Vanmarcke, E.H., "Simulated Earthquake Motions Compatible with Prescribed Response Spectra," M.I.T. Department of Civil Engineering Research Report R76-4, Order No. 527, January 1976.

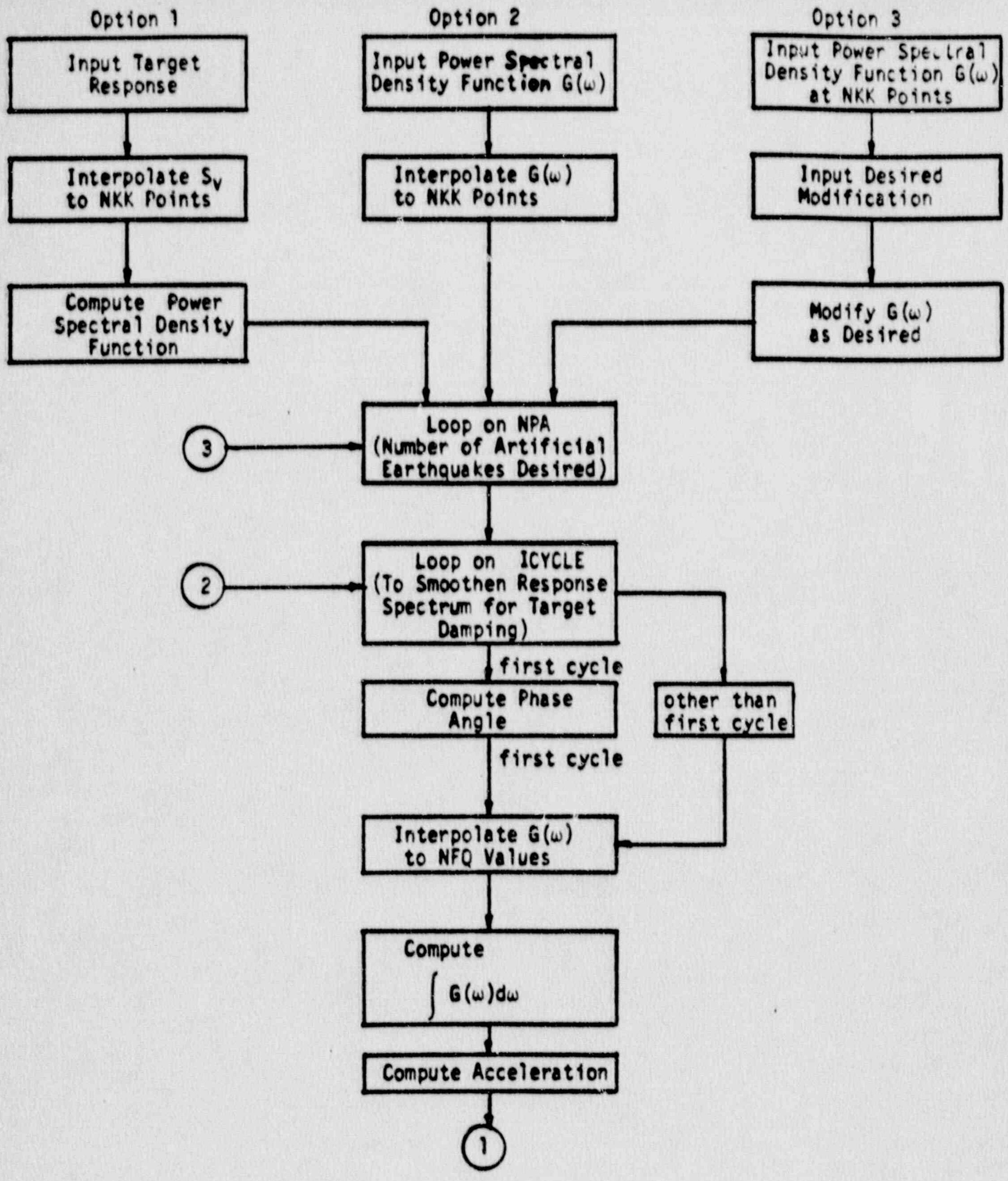


Fig. 1. Flowchart of SIMQKE

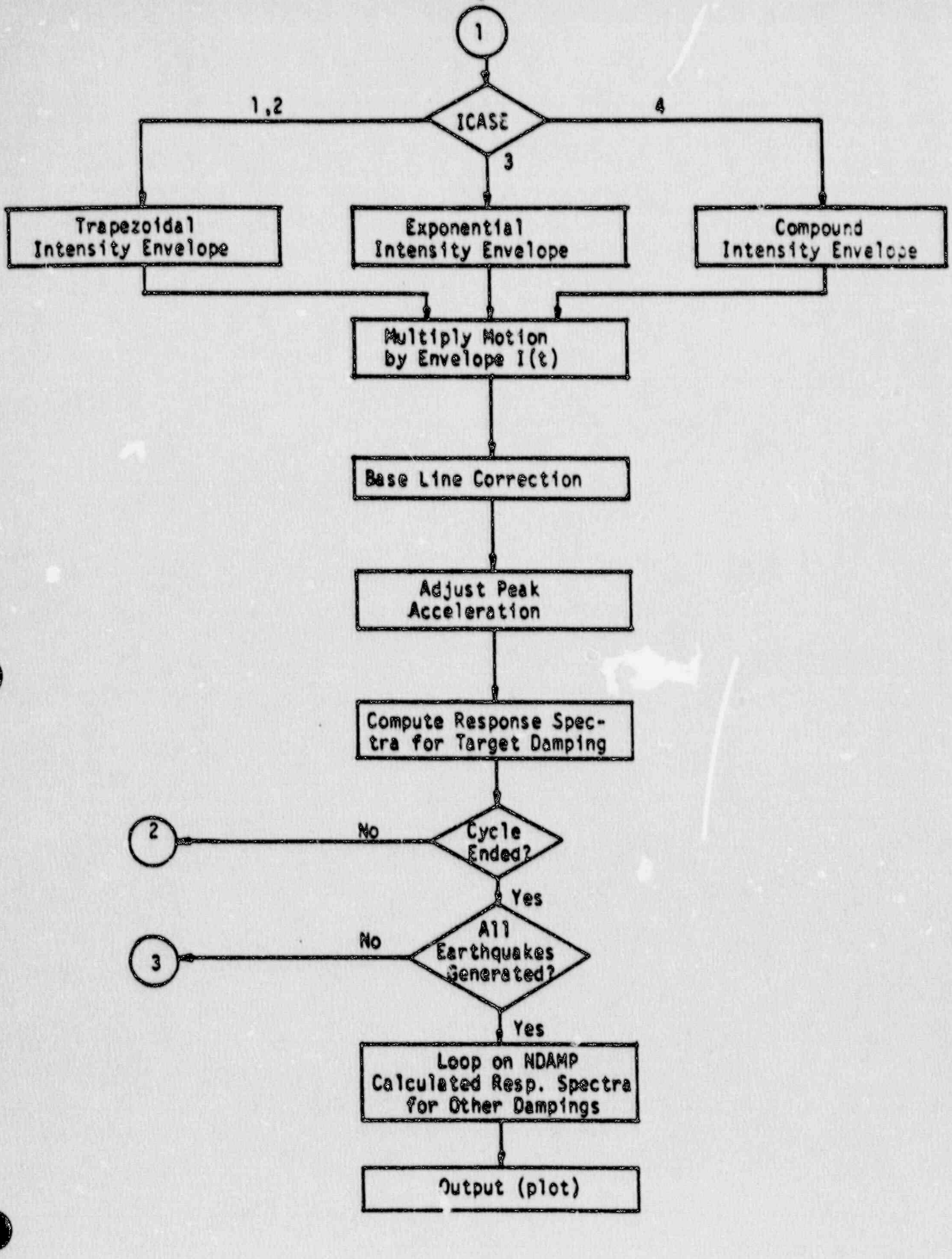
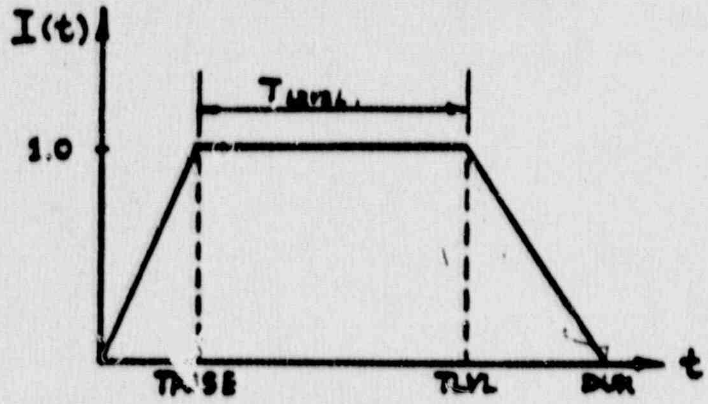


Figure 1 (Continued)

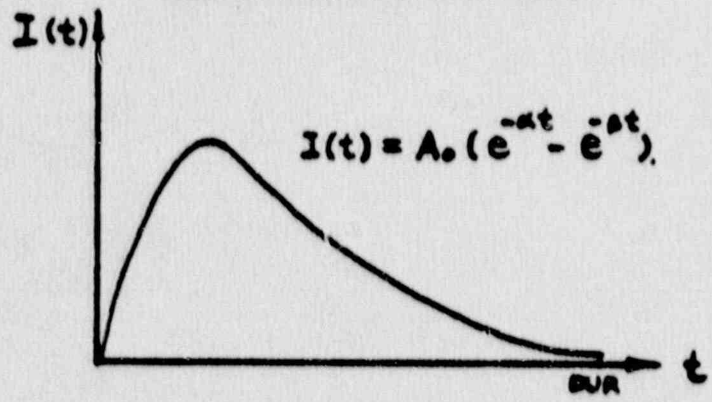
Option A : Trapezoidal



INPUT DATA:

1. ICASE = 2
2. TRISE
3. TLVL
4. DUR

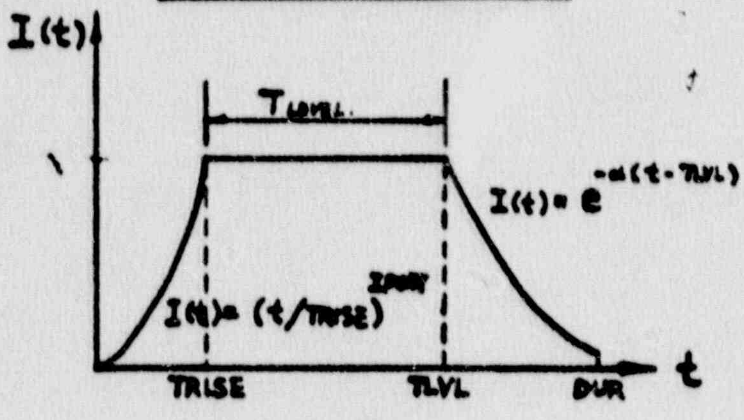
Option B : Exponential



INPUT DATA:

1. ICASE = 3
2. ALFAO
3. BETAO
4. AO
5. DUR

Option C : Compound



INPUT DATA:

1. ICASE = 4
2. TRISE
3. TLVL
4. IPOW
5. ALFAO
6. DUR

Figure 2

USER'S MANUAL

SIMQKE INPUT

The program SIMQKE can generally be used in three modes or options. In all options the primary output is an acceleration time-history, but in OPTION 1 the primary input is a target response spectrum; in OPTION 2 the spectral density function is directly specified; and OPTION 3 allows the user to re-input a previously generated power spectral density function and to specify desired changes in that function.

OPTION 1 - INPUT DATA

CARD 1 - FORMAT (20A4) TITLE CARD

CARD 2 - FORMAT (8G10.0)

- TS : smallest period (seconds) of desired response spectrum
- TL : largest period (seconds) of desired response spectrum
- TMIN1 : smallest period used to determine the range of frequencies to be represented in the simulation. Generally it is equal to TS.
- TMAX1 : largest period used to determine the range of frequencies to be represented in the simulation. Generally it is equal to TL.
- YMIN : an estimated smallest velocity response spectral value (in/sec). It is mainly used to determine the minimum ordinate on a plot of the spectrum.
- YMAX : an estimated largest velocity response spectral value (in/sec). It is used mainly to determine the maximum ordinate on a plot of the response.

CARD 3 - FORMAT (I5,6F10.4,I5)

- ICASE : If ICASE=1, no intensity envelope is used.
  - 2, trapezoidal intensity envelope is used.
  - 3, exponential intensity envelope is used.
  - 4, compound intensity envelope is used.
- TRISE : earthquake rise time (sec) of intensity envelope (when ICASE= 1,3; TRISE=0).
- TLVL : earthquake level time (sec) of intensity envelope (when ICASE= 1,3; TLVL=0).

DUR : desired duration of accelerogram

AO : parameter of exponential function (equals zero when ICASE=3).

ALFAO : parameter of intensity function (specifies when ICASE=3,4).

BETAO : parameter of intensity function (specifies when ICASE=3).

IPOW : parameter of compound intensity function (specifies when ICASE =4).

CARD 4 - FORMAT (2F10.4, I10, 8I5)

DELT : discretization interval (sec), standard input is 0.01 second.

AGMX : desired maximum ground acceleration in "g's".

IIX : an arbitrary odd integer which acts as a seed for the random phase angle generator.

NDAMP : number of damping values for which $S_v(\omega)$ is desired.

NCYCLE : number of cycles to smoothen a response spectrum. If NCYCLE=1, no cycling is made.

NPA : number of artificial earthquakes desired from one target response spectrum (with one spectral density function).

NKK : total number of periods at equal intervals on a logarithmic scale. 0 < NKK < 300 (generally NKK is on the order of 200 and 300).

NRES : total number of points which describe the target response spectrum.

NGWK : set NGWK=0 for OPTION 1

IPCH : if IPCH=0, no punched output is obtained.
if IPCH=1, punched output is obtained.

CARD 5 - FORMAT (8G10.0)

AMOR(I): damping coefficients in decimal parts of critical damping. The first damping entered will be the one for which cycling, if desired, will be done.

CARD 6 to CARD (5+NRES) - FORMAT (2F10.4) - Target response spectrum

TSV(1)	SVO(1)
⋮	⋮
TSV(NRES)	SVO(NRES)

NOTE : TSV(1) smallest period (sec).
TSV(NRES) largest period (sec).
SVO(1) target pseudo-velocity value in in/sec.
SVO(NRES) target pseudo-velocity value in in/sec.

OPTION 2 - (Earthquake is specified in terms of power spectral density)

CARD 1 - Same as in OPTION 1

CARD 2 - Same as in OPTION 1

CARD 3 - Same as in OPTION 1

CARD 4 - FORMAT (2F10.4, I10,8I5)

DELT : same as in OPTION 1

AGMX : same as in OPTION 1

IIX : same as in OPTION 1

NDAMP : same as in OPTION 1

NCYCLE : same as in OPTION 1

NPA : same as in OPTION 1

NKK : same as in OPTION 1

NRES : set NRES=0 for OPTION 2

NGWK : number of points that describe the power spectral density function

IPCH : same as in OPTION 1

CARD 5 - Same as in OPTION 1

CARD 6 to CARD (5 + NGWK): - FORMAT (2F10.4) - Input power spectral density function.

W O (1)	GWKO(1)
⋮	⋮
W O (NGWK)	GWKO(NGWK)

NOTE:

W O (1)	smallest frequency in rad/sec.
W O(NGWK)	largest frequency in rad/sec.
GWKO(1)	power spectral density.
GWKO(NGWK)	power spectral density.

OPTION 3 - (Input of a previously generated power spectral density function and desired changes).

CARD 1 - Same as in OPTION 1

CARD 2 - Same as in OPTION 1

CARD 3 - Same as in OPTION 1

CARD 4 - FORMAT (2F10.4, I10,8I5)

DELT : same as in OPTION 1

AGMX : same as in OPTION 1

IIX : same as in OPTION 1

NDAMP : same as in OPTION 1

NCYCLE : same as in OPTION 1

NPA same as in OPTION 1

NKK : is the negative number of periods for which the power spectrum is provided (e.g., - 300).

NRES : set NRES=0 for OPTION 3

NGWK : set NGWK = -1 for OPTION 3

IPCH : same as in OPTION 1

CARD 5 - Same as in OPTION 1

CARDS Previously punched output of power spectral density function values and corresponding periods at NKK points.

FORMAT : Periods TQ(I): (10F8.4) (Smallest Period First)

Power spectral density values GWK(I) : (6F13.3)

CARD FORMAT (2I10)

N2 : N2 = 1 denotes that some portions of the GWK array are to be modified.

N2=0 denotes that no such modifications are desired.

N3 : denotes the number of portions of the GWK array which are to be modified.

CARD FORMAT (2F10.4) - if individual values of GWK must be changed, the following cards contain first the period and then the corresponding new value of GWK. These local changes are terminated by a card with 99. in the first field. If no local changes are desired, only the 99. card is entered.

Assuming no local changes, the following card will be:

CARD FORMAT (8G10.4) - the following cards are read only if N2=1 and N3 > 0.

TQ1 : beginning period (sec).

TQ2 : ending period (sec).

RATIO : ratio by which GWK values from period TQ1 to TQ2 will be multiplied.

Sample Data

Duration - 20 sec.

Maximum Ground Acceleration - 1.0g

Intensity Envelope Function being used - Trapezoidal (As Fig. 3).

Target Response Spectrum - A design response spectrum for ζ = 0.02 as shown in TABLE I.

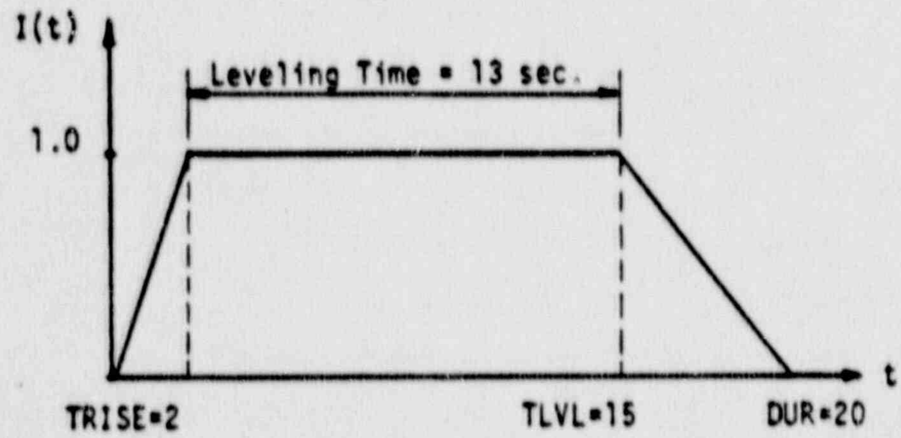


Figure 3

TSV (sec)	SVO (in/sec)
0.0143	1.0
0.0263	1.9
0.1064	22.0
0.2444	75.0
3.333	95.0
5.0	60.0

Table I

Input Data:

CARD 1 : TI E

CARD 2 : TS = 0.02 sec.

TL = 3.0 sec.

TMIN1 = 0.02 sec.
TMAX1 = 3.0 sec.
YMIN = 0.1 in/sec.
YMAX = 500.0 in/sec.

CARD 3 : ICASE = 2 (Using Trapezoidal Intensity Function)
TRISE = 2.0 sec.
TLVL = 15.0 sec.
DUR = 20.0 sec.
AO = 0.0
ALFAO = 0.0
BETAO = 0.0
IPOW = 0

CARD 4 : DELT = 0.01 sec.
AGMX = 1.0G
IIX = 1235
NDAMP = 3 (for 0.02, 0.05, 0.1)
NCYCLE = 2
NPA = 1
NKK = 200
NRES = 6
NGWK = 0
IPCH = 0

CARD 5: AMOR(1) = 0.02, AMOR(2) = 0.05, AMOR(3) = 0.1, which are the damping value. Note that the first one is the target damping.

CARD 6 - CARD 11, as in TABLE I.

Output Data:

The calculated spectral density function is shown on Fig. 4, The response spectra are shown on Figs. 5 , 6 and 7 , for damping ratios of 0.02, 0.05, and 0.10, respectively. Furthermore, the target response spectrum for damping 0.02 is shown on each plot.

SPECTRAL DENSITY FUNCTION

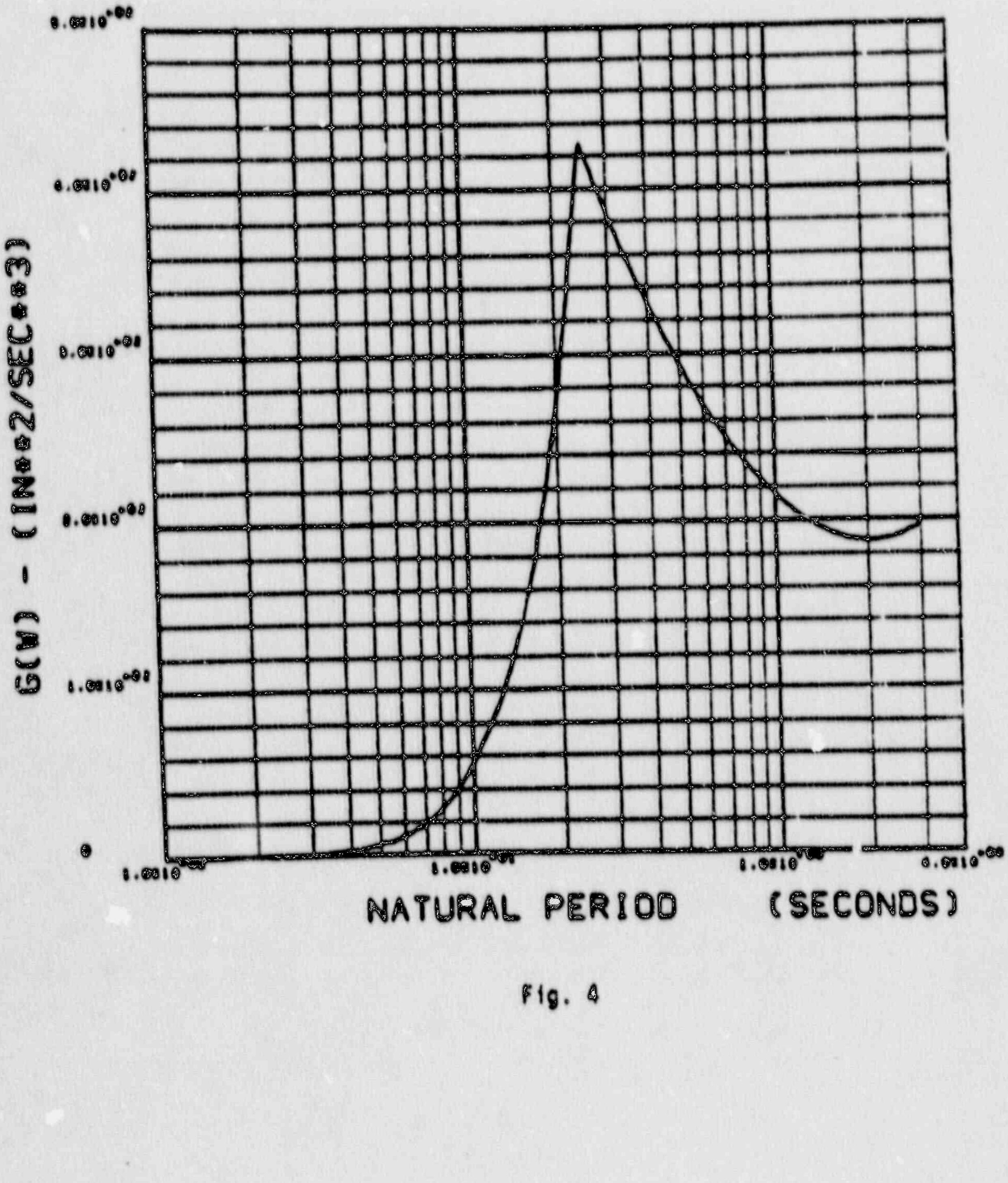


Fig. 4

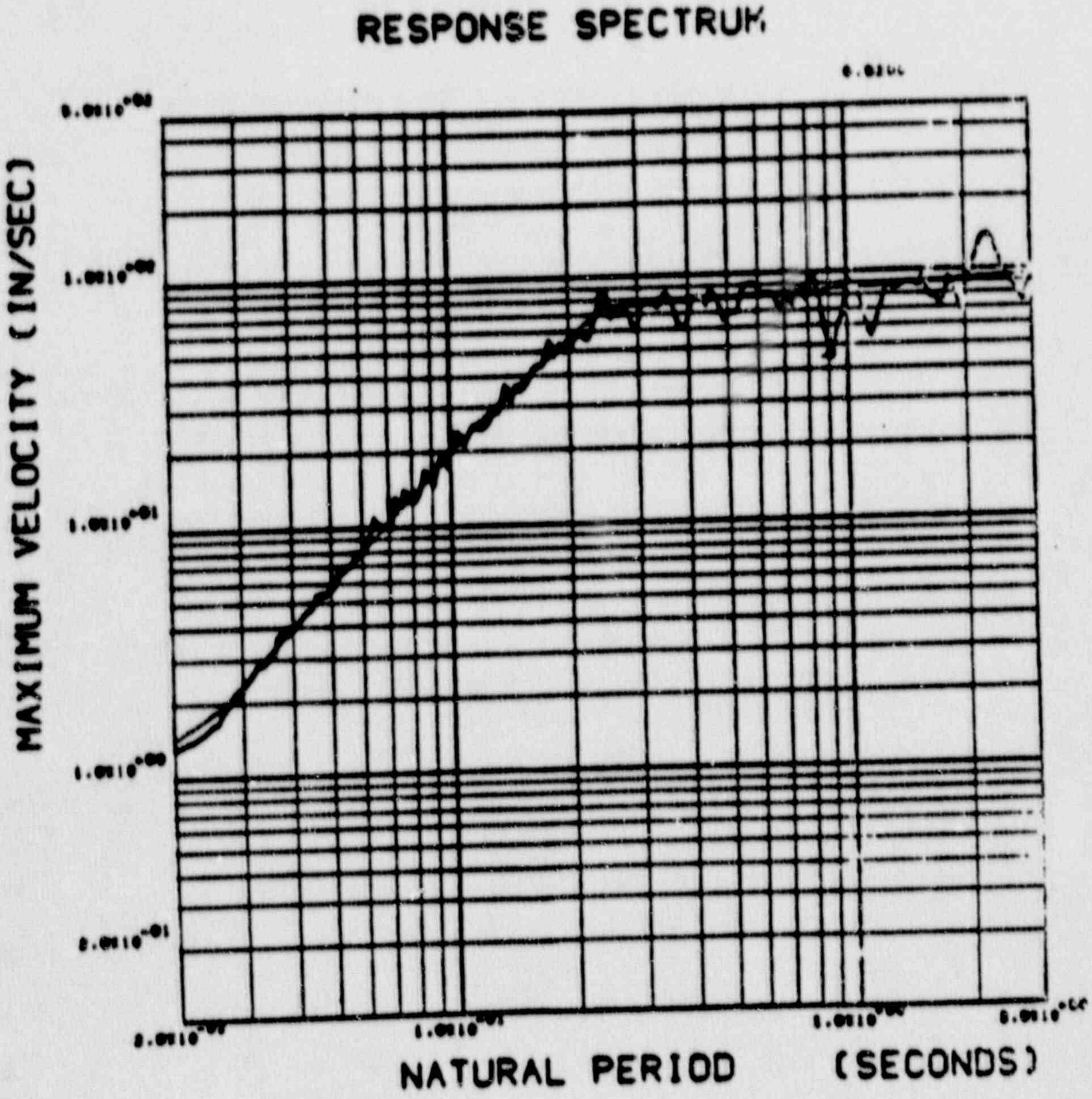


Fig. 5 ($\xi = 0.02$)

Target response spectrum and calculated response spectrum for 2% damping

RESPONSE SPECTRUM

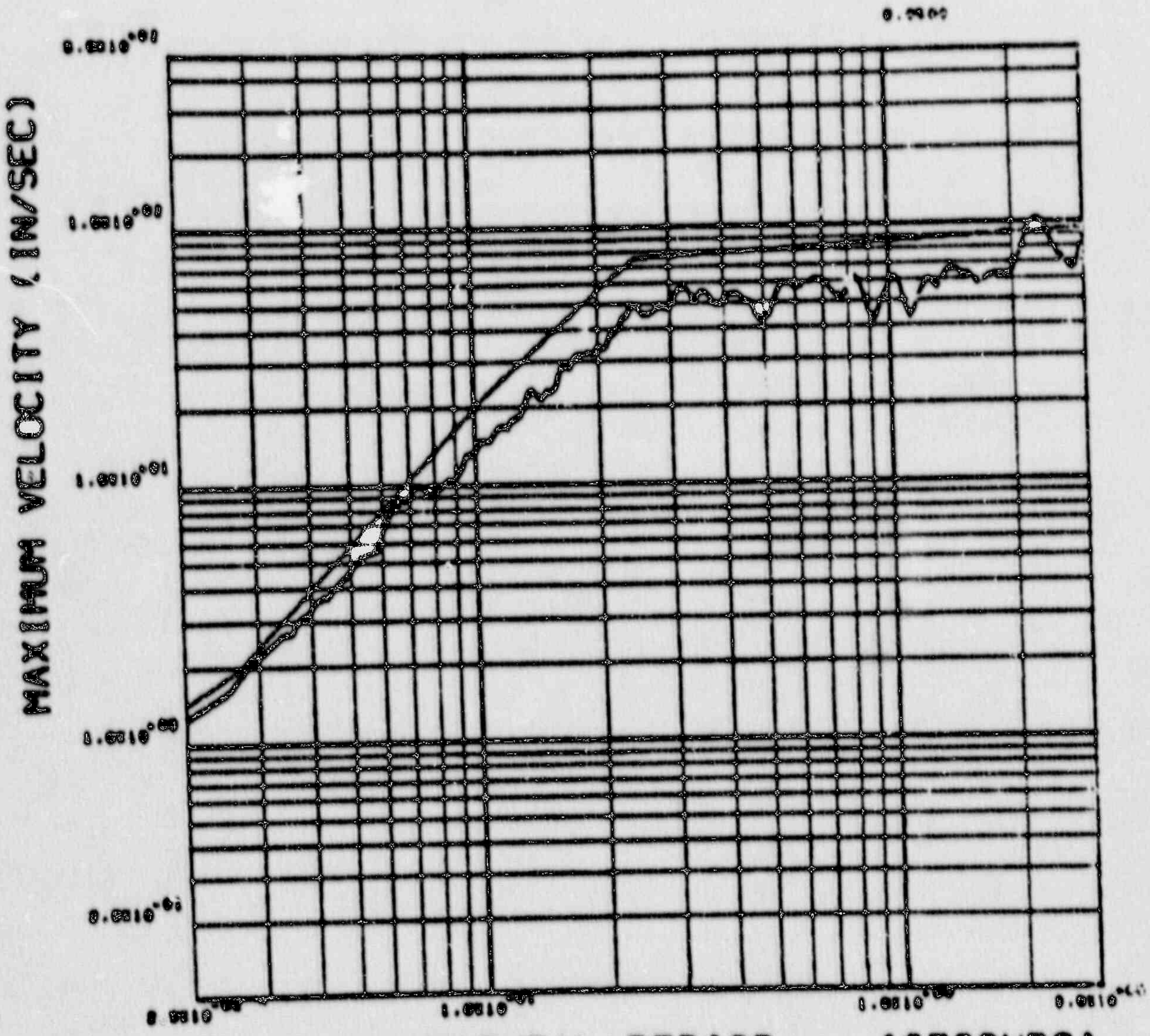


Fig. 6 (ξ = 0.05)

Calculated response spectrum for 5% damping and 2% damped target response spectrum.

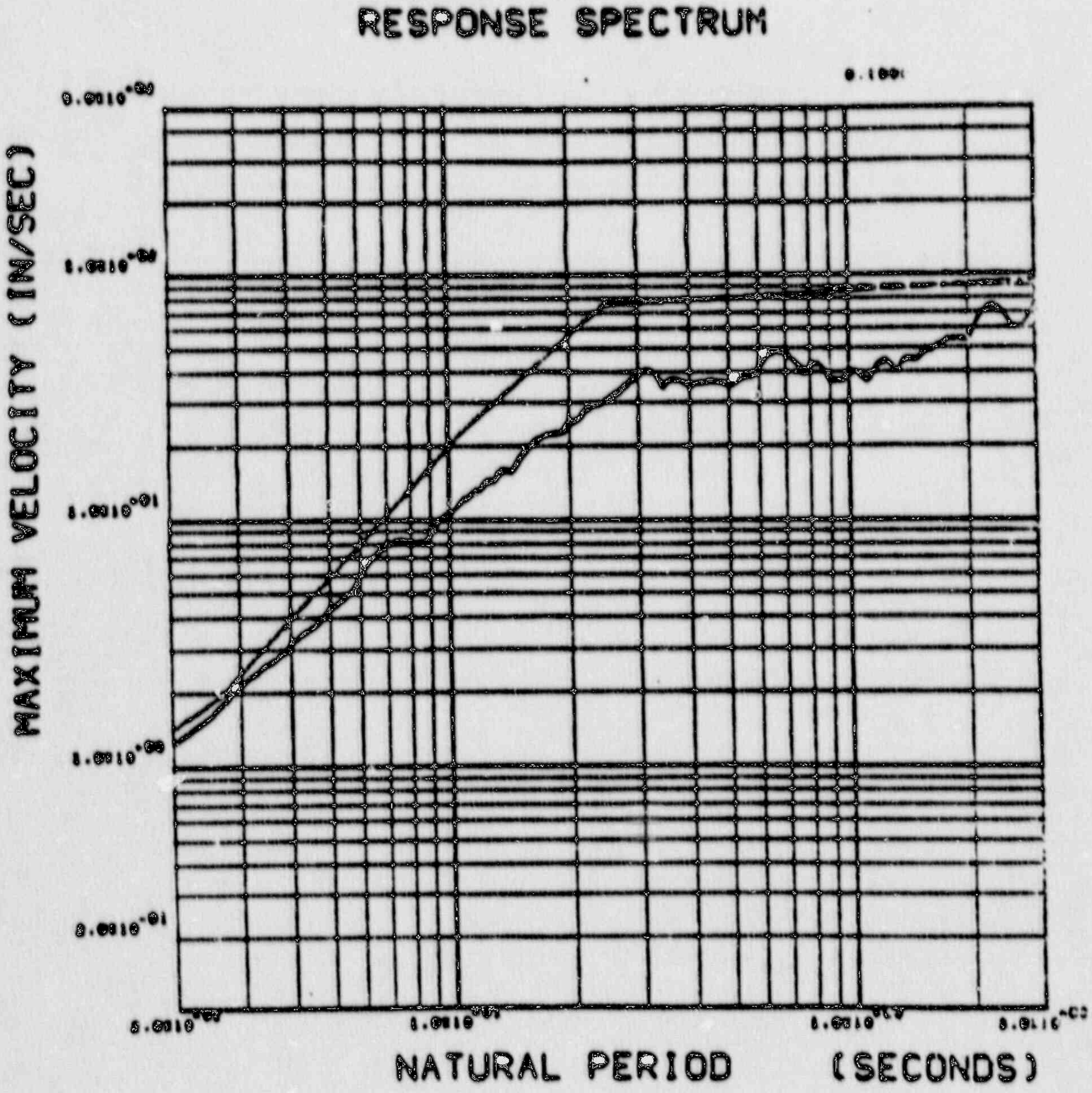


Fig. 7 (ξ = 0.1)

Calculated response spectrum for 10% damping and
2% damped target response spectrum.

```
// 'SHIH-SHENG LAI',CLASS=C,REGION=200K
/*SRI WEEKLY
/*MAIN TIME=10,LINES=10
// EXEC FORCLG,LIBRARY='SYS5.SC4020.SUBR'
//C.SYSIN  DD  *
C      SIMOKE - A PROGRAM FOR EARTHQUAKE SIMULATION
C
C INPUT PARAMETERS REQUIRED
C
C  IX--A STARTER FOR THE RANDOM NUMBER GENERATOR-IT MUST BE ODD
C NPA---NUMBER OF DIFFERENT MOTIONS REQUIRED
C ICASE---=1 FOR STATIONARY CASE
C  TL - THE LARGEST PERIOD VALUE FOR RESPONSE CALCULATIONS
C  TS - THE SMALLEST VALUE
C  TMIN,TMAX---OPTIONAL MINIMUM AND MAXIMUM PERIODS TO DETERMINE FREQUENCY
C  CONTENT OF THE MOTION, DEFAULT USES TS AND TL
C  NCYCLE---THE NUMBER OF ITERATIONS TO BE PERFORMED IS ONE LESS
C  THAN THIS NUMBER--IF NCYCLE = 1, NO ITERATION IS MADE
C  DELT -- TIME INTERVAL USED BETWEEN POINTS
C  NDAMP---NUMBER OF DIFFERENT DAMPINGS TO BE CONSIDERED
C  AMOR---ARRAY CONTAINING THE DAMPING VALUES
C  TRISE --- RISE TIME
C  TLVL --- INTERVAL AT THE HIGHEST AMPLITUDE
C  NGWK -- DEFINES TYPE OF SPECTRAL DENSITY FUNCTION USED
C  IF NGWK = 0 , THE PROGRAM GENERATES ITS OWN POWER SPECTRUM.
C  IF NGWK IS NOT = 0, THEN A PIECEWISE LINEAR POWER SPECTRUM
C  WILL BE PROVIDED BY USER AND NGWK = NUMBER OF POINTS THAT DEFINE IT.
C  IF NGWK IS NEGATIVE, THEN GWK WILL BE READ ALONG WITH PERIODS FOR
C  RESPONSE CALCULATIONS
C  ABS(NKK) = NUMBER OF POINTS FOR RESPONSE CALCULATIONS.
C  IF NKK IS POSITIVE, THE PROGRAM WILL GENERATE A STRING OF POINTS
C  ON A LOGARITHMIC SCALE FROM TS TO TL.
C  IF NKK IS NEGATIVE, THE USER PROVIDES A LIST OF POINTS.
C  (TSV,SVO) - POINTS WHICH DEFINE DESIRED VELOCITY RESPONSE SPECTRUM
C  NRES---NUMBER OF POINTS WHICH DEFINE DESIRED RESPONSE SPECTRUM
C  IF NRES = 0, NO DATA NEED BE GIVEN(NO CYCLING ONLY).
C  (WO,GWKO) - POINTS THAT DEFINE POWER SPECTRUM IF NGWK IS NOT = 0.
C  TO---OPTIONAL ARRAY OF PERIOD VALUES FOR RSPONSE CALCULATIONS.
C  AGMX --- MAX GROUND ACC  INPUT UNIT IN G
C  DUR --- DURATION
C  UNITS   SECONDS,INCHES---UNLESS SPECIFIED OTHERWISE
C
       DIMENSION TOI(150)
      DIMENSION YTITL(9),TITLO(9)
      DIMENSION TIT(9),TIM(9),TIMX(9),TIMY(9),TIX(9),TITX(9),TITY(9)
      DIMENSION ACCG(8001),WB(300),GWK(300),TIME(3001),FRO(300),
     1          TQ(300),PLTVMX(10,300),AMOR(10),TITLE(20),IBUF(2000),
     2          FO(1500),GWG(1500),PA(1500),DW(1500),TMD(10,300),
     3          WO(300),GWKO(300),SV(300),TSV(1010),SVO(1010),SI(300)
     *          ,ANEWGK(300)
      DIMENSION PERCEN(300)
      EQUIVALENCE(TIME(1),FO(1)),(TIME(1501),DW(1)),(GWG(1),PLTVMX(1))
      DATA TIX/'    ','    ','RESP','ONSE',' SPE','CTRU','M   ','    ',
     $'    '/
      DATA TIM/'    ','    ','ACCE','LERO','GRAM','    ','    ','    ',
     $ '    '/
      DATA BLANK/'    '/
      DATA TIT/'RESP','ONSE',' SPE','CTRU','M  D','AMPI','NG =','    ',
     $    '/
      DATA TITX/'    ','  NA','TURA','L PE','RIOD','    ',' (SEC','ONDS',
```

```
     $')    '/
      DATA YTITL/'    ','G(W)','' - (','IN**','2/SE','C**3',')    '/
      DATA TITLO/'SPEC','TRAL',' DEN','SITY',' FUN','CTIO','N    ','    '
     $,'    '/
      DATA TITY/'    ','    ','MAXI','MUM ','VELO','CITY',' (IN','/SEC',
     $')    '/
      DATA TIMX/'    ','    ','TIME',' (SE','COND','S)  ','    ','    ',
     $'    '/
      DATA TIMY/'    ','ACCE','LERA','TION','    ',' G''S','    ','    '
     $ '    '/
      DATA BETAS,BETAL/0.005,0.2/,PI/3.14159/
      ICONT=0
C
C                 REQUIRED INPUT PARAMETERS.
C
 9003 READ (5,1) TITLE
      CALL STOIDV ('M5324-9950',9,0)
    1 FORMAT (20A4)
      READ (5,7020) TS,TL,TMIN1,TMAX1,YMIN,YMAX
 7020 FORMAT(8G10.0)
      READ (5,3020) ICASE,TRISE,TLVL,DUR,AD,ALFAO,BETAO,IPOW
 3020 FORMAT (I5,6F10.4,I5)
      READ (5,129) DELT,AGMX,IIX,NDAMP,NCYCLE,NPA,NKK,NRES,NGWK,IPCH
  129 FORMAT (2F10.4,I10,8I5)
      AGMX=AGMX*32.2*12.
 4262 FORMAT (2F10.4)
C
C     FIRST DAMPING VALUE MUST BE ONE WHICH IS CYCLED ON.
C     THE FIRST CURVE VALUE WILL BE PLOTTED(RESPONSE SPECTRUM)
C
      READ(5,7020) (AMOR(I),I=1,NDAMP)
      WRITE (6,2) TITLE
    2 FORMAT(1H1,//,2X,20A4)
      WRITE(6,30) DELT
   30 FORMAT(//7X,'TIME INCREMENT = ',F5.3)
      IF (NKK.LE.0) GO TO 6301
      CALL PLTX2(TS,TL,TO,NKK)
      GO TO 3
 6301 NKK=-NKK
C
C   OPTIONAL INPUT PARAMETERS    IF NKK IS NEGATIVE.
C   GWK IS REQUIRED ONLY IF NGWK IS NEGATIVE
C
      READ (5,13) (TO(I),I=1,NKK)
      READ (5,888)(GWK(NKK-I+1),I=1,NKK)
      READ (5,7020) N2,N3
   14 READ (5,4262) TC,GWC
      IF (TC.GT.50.0) GO TO 5
      DO 9 I=1,NKK
      IF (ABS(TC-TO(I)).LT.0.0002) GO TO 11
    9 CONTINUE
      GO TO 14
   11 GWK(NKK-I+1)=GWC
      GO TO 14
    5 CONTINUE
      IF (N2.EQ.0) GO TO 3
      DO 10 I=1,N3
      READ (5,7020) TO1,TO2,RATIO
      DO 10 J=1,NKK
      IF (TO(J).GT.TO1.AND.TO(J).LT.TO2) GWK(NKK-J+1)=GWK(NKK-J+1)*RATIO
```

```
   10 CONTINUE
    3 DO 4325 I=1,NKK
      J=NKK-I+1
      FRQ(I)=1./TQ(I)
 4325 WB(J)=6.2832/TQ(I)
      IF (TMIN1.EQ.0.)  TMIN1=TS
      WL=6.2832/TMIN1
      IF (TMAX1.EQ.0.)  TMAX1=TL
      WS=6.2832/TMAX1
C
C      WEND --- THE HIGHEST FREQ FOR GROUND MOTION
C      WBEGIN --- THE LOWEST FREQ FOR GROUND MOTION
C     THE FOLLOWING OPTIONS FOR COMPUTING WEND AND WBEGIN MAY BE ELIMINATED
C     SINCE BETAL AND BETAS HAVE BEEN DEFINED INTERNALLY BY THE PROGRAM TO BE
C     .2 AND .005 RESPECTIVELY
C
      WEND=2.0*WL
      IF ((5.0*BETAL).GE.1.0) WEND=WL*(1.+5.*BETAL)
      WBEGIN=WS*.5
      IF (BETAL.LT.0.05)  WBEGIN=WS*(1.-10.*BETAL)
      IF(ICASE.GT.1) GO TO 42
      WRITE(6,136)
  136 FORMAT(7X,15HSTATIONARY CASE)
      GO TO 38
   42 WRITE(6,135)
  135 FORMAT(7X,59HNON-STATIONARY IN INTENSITY BUT STATIONARY IN FREQ SP
     /ECTRUM)
   38 WRITE(6,106)AGMX
  106 FORMAT(7X,'EXPECTED MAXIMUM GROUND ACC =',F7.2,' IN./SEC./SEC.')
      IF (NRES.EQ.0) GO TO 6022
      READ(5,4262) (TSV(I),SVO(I),I=1,NRES)
      CALL POLATE(NRES,NKK,TSV,SVO,TQ,SV)
      WRITE(6,107) TRISE,TLVL,DUR
  107 FORMAT(7X,'TRISE =',F7.2,'  TLEVEL =',F7.2,'  DURATION =',F7.2)
      WRITE(6,6016)
 6016 FORMAT (//,11X,'ORIGINAL POWER SPECTRUM',//,11X,'PERIOD',8X,
     8'FREQUENCY',7X,'SPECTRUM',12X,'R'//)
 6022  IF (NGWK.EQ.0) GO TO 4260
       IF(NGWK.LT.0) GO TO 9703
C
C     OPTIONAL INPUT OF ORIGINAL POWER SPECTRUM IF NGWK IS POSITIVE
C     IF TQ WAS READ IN PREVIOUSY FOR NKK NEGATIVE. THIS OVERIDES POWER
C     SPECTRUM 'GWK' READ IN WITH 'TQ'.
C
C
C     OPTIONAL INPUT OF DESIRED RESPONSE VELOCITY SPECTRUM IF CYCLING IS USED.
C
       READ (5,4262) (WO(I),GWKO(I),I=1,NGWK)
       CALL POLATE(NGWK,NKK,WO,GWKO,WB,GWK)
 9703  DO 8011 I=1,NKK
       J=NKK+1-I
       GWKO(I)=GWK(I)
 8011  WRITE(6,4360) TQ(I),FRQ(I),GWK(J)
       GO TO 6007
 4260  T=(DUR+TLVL)/2.
       BETA=AMOR(1)
       CALL SVGW(NKK,WB,GWKO,SV,T,BETA,16.0,0.6,0.368,GSUM,WCP,QP,RR)
       DO 6001 LLL=1,NKK
       LL1=NKK-LLL+1
 6001  WRITE(6,8901)TQ(LL1),FRQ(LL1),GWKO(LLL),RR(LLL)
```

```
      WRITE (6,8902) WCP,OP
 8902 FORMAT (//,10X,' CENTRAL FREQUENCY WC =  ',F10.3,//,10X,' DISPERSIO
     SN PARAMETER  O=  ',F10.3,/)
      SET THE MAXIMUM VALUE OF SPECTRAL DENSITY FUNTION FOR PLOT
      XMAX= 0.0
      DO 327 I12= 1,NKK
      IF (XMAX-GWKO(I12)) 326,327,327
  326 XMAX=GWKO(I12)
  327 CONTINUE
      IF (XMAX-70.0) 329,328,328
  328 XLAI=XMAX/100.
      NDUM= (HFIX(XLAI)+1)*100
      XMAX=DFLOAT(NDUM)
      GO TO 330
  329 XMAX=70.0
  330 CONTINUE
      CALL GWPLOT (NKK,0.01,4.0,0.0,XMAX,TO,GWKO,TITX,TITLO,YTITL)
      AREA=SQRT(GSUM)/386.4
      WRITE(6,6008) AREA
 6008 FORMAT (/11X,'STANDARD DEVIATION OF PROCESS = ',F7.4,' G''S')
 6007 ITOTAL=NDAMP*NKK
      IX=(IIX/2)*2+1
      DO 585 NTOTAL=1,NPA
      WRITE(6,60) IX
   60 FORMAT('1',//10X,'A NEW PHASE ANGLE SET WITH SEED = ',I10)
      DO 8608 I=1,NKK
 8608 GWK(I)=GWKO(I)
      MM=1
      AREAG=0.
      SIGMS=0.
      NFO=0
      W=WBEGIN
 4080 DELW=BETAS*W
      W=W+DELW
      CALL DUMMY(W,FOUT,NKK,WR,GWK,MM)
      NFO=NFO+1
      GWG(NFO)=FOUT
      FO(NFO)=W
      DW(NFO)=DELW
      AREAG=AREAG+GWG(NFO)*DELW
      SIGMS=SIGMS+GWG(NFO)*DELW*W*W
      IF (W.LT.WEND) GO TO 4080
      DO 100 ICYCLE=1,NCYCLE
C
C     W IS LOWEST FREQUENCY REPRESENTED IN GROUND MOTION.
C
      IF (ICYCLE.LE.1) GO TO 1116
      AREAG=0.
      MM=1
      DO 6703 I=1,NFO
      W=FO(I)
      CALL DUMMX(W,FOUT,NKK,WR,GWK,MM)
      GWG(I)=FOUT
 6703 AREAG=AREAG+DW(I)*GWG(I)
 1116 DO 1117 IP=1,NFO
 1117 GWG(IP)=GWG(IP)*DW(IP)*2.
      IF(ICYCLE.GT.1) GO TO 8603
C
C     COMPUTE AVERAGE FREQUENCY AND PERIOD
C
```

```
      SIGMS=SIGMS/AREAG
      WA=SQRT(SIGMS)
      TA=6.2832/WA

      DEFINE SLOPES OF ENVELOPE

      IF (ICASE.GT.2) GO TO 6
      IF(TRISE.GT..0) GO TO 33
      TRISE=0.25*DUR
      TLVL=0.
   33 IF(ICASE.LE.1) GO TO 7
    8 FTC1=1./TRISE
      FTC2=-1./(DUR-TRISE-TLVL)
      GO TO 6
    7 FTC1=0.5
      FTC2=0.
    6 WRITE(6,114) WA,TA,NFO,WBEGIN,WEND
  114 FORMAT(//10X,'CENTRAL CIRCULAR FREQUENCY = ',F10.4,' RADIANS/SEC.'
     $//10X,'CENTRAL PERIOD = ',F8.4,' SECONDS'
     $//10X,'NUMBER OF PHASE ANGLES = ',I5
     $//10X,'LOWEST FREQUENCY IN MOTION = ',F10.5,' RADIANS/SEC'
     $//10X,'HIGHEST FREQUENCY IN MOTION = ',F10.5,' RADIANS/SEC.')
C
C      COMPUTE RANDOM PHASE ANGLES
C
       DO 31 I=1,NFO
       IV=IX*65539
       IF (IV.GE.0.) GO TO 32
       IV=IV+2147483647+1
   32  Y L=IY
       YFL=YFL*.4656613E-9
       PA(I)=6.2832* YFL
   31  IX=IY
C
C      ACCELERATION COMPUTATIONS
C
 8603  NACCG=DUR/DELT+1.000001
       IF(NCYCLE.LE.ICYCLE) GO TO 9801
       WRITE(6,9567)
 9567  FORMAT(1H1,9X,'PERIOD',8X,'FREQUENCY',6X,'POW.SPEC.DEN.',5X,
     $'DES.RESPONSE',6X,'CAL.RESPONSE',7X,'DIFFERENCE',9X,'TIME',//)
       WRITE(6,9008) ICYCLE,TO(1)
 9008  FORMAT(30X,'CYCLE NUMBER ',I2,20X,'LOWEST MODIFIED PERIOD = ',
     $F10.4,' SECONDS'//)
 9801  DO 1114 KK=1,NACCG
 1114  ACCG(KK)=0.
       KCHEK=1000
       DO 12   LM=1,NFO
       IF (GWG(LM).LT.0.0) WRITE (6,3000) GWG(LM),LM
       GWG(LM)=ABS(GWG(LM))
 3000  FORMAT (' GWG NEGATIVE, EQUALS ',E10.3,' FOR LM OF ',I5)
       AA=SQRT(GWG(LM))
       ALFA=FQ(LM)*DELT
       SINA=SIN(ALFA)
       COSA=COS(ALFA)
       SN=SIN(PA(LM))
       CN=COS(PA(LM))
       SNA=SINA*CN+COSA*SN
       CNA=COSA*CN-SINA*SN
       ACCG(2 =AA*SNA+ACCG(2)
```

```
      DO 12   KK=3,NACCG
      IF (KK.GE.KCHEK) GO TO 5012
      SNO=SNA
      SNA=SNA*COSA+CNA*SINA
      CNA=CNA*COSA-SNO*SINA
      GO TO 12
 5012 KCHEK=KCHEK+1000
      SNA=SIN(PA(LM)+(KK-1)*ALFA)
      CNA=COS(PA(LM)+(KK-1)*ALFA)
   12 ACCG(KK)=AA*SNA+ACCG(KK)
C     APPLY INTENSITY FUNTION WITH FOUR OPTION
      GO TO (3003,3003,3006,3007),ICASE
 3003 IF(ICASE.LE.1) GO TO 18
      TX=TRISE
      GO TO 19
   18 TX=2.
C
C     DEFINE MAXIMUM HEIGHTS IN TERMS OF SLOPES
C
   19 DO 16 KK=2,NACCG
      TI=(KK-1)*DELT
      IF (TI.GT.TX) GO TO 15
      FT=FTC1*TI
      GO TO 16
   15 IF(ICASE.LE.1) GO TO 28
      IF((TI-TX-TLVL).GT.0.) GO TO 29
   28 FT=1.
      GO TO 16
   29 FT=1.+(TI-TX-TLVL)*FTC2
C
C     COMPUTE ACCELERATION
C
   16 ACCG(KK)=ACCG(KK)*FT
      GO TO 3011
 3004 DO 3006 KK=2,NACCG
      TI=(KK-1)*DELT
      FT=AD*(EXP(-ALFAD*TI)-EXP(-BETAD*TI))
 3006 ACCG(KK)=ACCG(KK)*FT
      GO TO 3011
 3007 DO 3010 KK= 2,NACCG
      TI=(KK-1)*DELT
      IF(TI.GE.TRISE) GO TO 3008
      FT=(TI/TRISE)**IPOW
      GO TO 3010
 3008 IF ((TI-TLVL-TRISE).LT.0.) GO TO 3009
      FT=EXP(-ALFAD*(TI-TLVL))
      GO TO 3010
 3009 FT=1.0
 3010 ACCG(KK)=ACCG(KK)*FT
 3011 CONTINUE
C
C COMPUTE MAX GROUND ACC BEFORE BASELINE CORRECTION
C
   20 AMAXIM=0.
      DO 5000 I=1,NACCG
      IF(ABS(ACCG(I)).LT.ABS(AMAXIM)) GO TO 5000
      AMAXIM=ACCG(I)
      TMAXIM=(I-1)*DELT
 5000 CONTINUE
      IF (NCYCLE.GT.ICYCLE) GO TO 8506
```

```
      WRITE(6,5200) AMAXIM,TMAXIM
 5200 FORMAT(1H ,//,10X,'MAX. ACCEL. BEFORE CORRECTION',F12.5//
     $ '          AT TIME',F12.5//)
 8504 TI=-DELT*0.5
C
C     JUSTIFY ACCG TO ZERO FINAL VELOCITY
C
      BETA1=0.
      BETA2=0.
      BETA3=0.
      VEL=0.
      DO 4300 IZ=1,NACCG
      VEL=VEL+ACCG(IZ)*DELT
      TI=TI+DELT
      BETA1=BETA1+VEL*TI
      BETA2=BETA2+VEL*TI*TI
 4300 BETA3=BETA3+VEL*TI*TI*TI
      BETA1=BETA1*DELT/(TI*TI*TI)
      BETA2=BETA2*DELT/(TI*TI*TI*TI)
      BETA3=BETA3*DELT/(TI*TI*TI*TI*TI)
      C1=300.*BETA1-900.*BETA2+630.*BETA3
      C2=(-1800.*BETA1+5760.*BETA2-4200.*BETA3)/TI
      C3=(1890.*BETA1-6300.*BETA2+4725.*BETA3)/(TI*TI)
      DO 4310 IZ=1,NACCG
      TI=(IZ-1)*DELT
 4310 ACCG(IZ)=ACCG(IZ)-C1-C2*TI-C3*TI*TI
C
C     GET MAX GROUND ACC
C
      GAMX=ACCG(1)
      VEL=0.
      VAMX=0.
      DISP=0.
      DMAX=0.
      LL1=0
      GAMX=ABS(GAMX)
      DO 59 LL=2,NACCG
      GAMY=ABS(ACCG(LL))
      VEL=VEL+ACCG(LL)*DELT
      DISP=DISP+VEL*DELT
      DAMY=ABS(DISP)
      VAMY=ABS(VEL)
      IF (DAMY.LE.DMAX) GO TO 52
   53 DMAX=DAMY
   52 IF (VAMY.LE.VAMX) GO TO 56
      VAMX=VAMY
   56 IF(GAMY.LE.GAMX) GO TO 59
   58 GAMX=GAMY
      LL1=LL
   59 CONTINUE
C     NO SCALING OF THE ENTIRE TIME HISTORY IS DONE BUT PEAKS ARE ADJUSTED
C     IN ORDER TO HAVE ONLY ONE PEAK EQUAL TO THE SPECIFIED MAX GROUND ACC
      TTT=ABS(GAMX/AGMX)
      IF(TTT.LE.1.) GO TO 1112
      DO 111 K1=1,NACCG
      DAR=ABS(ACCG(K1))-AGMX
      IF(DAR.LE.0.) GO TO 111
      ACCG(K1)=ACCG(K1)/TTT
  111 CONTINUE
      GO TO 1113
```

```
 1112 ACCG(LL1)=ACCG(LL1)/TTT
 1113 GAMX=AGMX/386.4
      LIM=NDAMP
      IF (ICYCLE.LT.NCYCLE) LIM=1
C
C     CHECK ACCG DIMENSIONS
C
      ICK=NACCG+2.*TO(NKK)/DELT
      IF (ICK.GE.8000) WRITE (6,34) ICK
   34 FORMAT ('  ACCG ARRAY NOT ENOUGH FOR NACCG+2*(LARGEST PERIOD)/DT =
     $ ',I5)
      IF (ICK.GE.8000) GO TO 9003
C
C     RESPONSE CALCULATION AND PLOTTING
C
      CALL SPECT(PLTVMX,TMD,ACCG,NACCG,DELT,TO,NKK,AMOR,LIM)
      IF (IPCH.EQ.0) GO TO 35
      WRITE (7,27) ICYCLE
   27 FORMAT ('GWK FOR CYCLE ',I2)
      WRITE (7,888)(GWK(NKK-I+1),I=1,NKK)
  888 FORMAT (6F13.3)
   35 CONTINUE
      IF(NCYCLE.LE.ICYCLE) GO TO 44
C
C     CYCLING PROCEDURE WHICH MODIFIES G(W) TO SMOOTHEN THE CALCULATED
C     RESPONSE SPECTRUM
C
      SUMPOS = 0.
      SUMNEG = 0.
      DO 43 I=1,NKK
      AMULT=SV(I)/PLTVMX(1,I)
      RATIOS = ABS (1./AMULT)*100.
      PERCEN(I) =      RATIOS - 100.
      WRITE(6,8901) TO(I),FRQ(I),GWK(NKK-I+1),SV(I),PLTVMX(1,I),
     * PERCEN(I),TMD(1,I),I
 8901 FORMAT (5(4X,F12.3),4X,F12.1,' %',4X,F12.3,I10)
      J=NKK-I+1
10002 ANEWGK(J) = GWK(J)*AMULT*AMULT
      AINCRM = ANEWGK(J)-GWK(J)
      IF (AINCRM.GE.0.) SUMPOS = SUMPOS+AINCRM
      IF (AINCRM.LT.0.) SUMNEG = SUMNEG-AINCRM
   43 CONTINUE
      IF (SUMNEG.LE.1.E-8) GO TO 213
      FACTOR = SUMPOS/SUMNEG
      WRITE (6,10000) SUMPOS,SUMNEG,FACTOR
10000 FORMAT (//10X,'SUMPOS =',F12.3,10X,'SUMNEG =',F12.3,10X,'FACTOR ='
     * ,F12.3)
      DO 211  I=1,NKK
  211 GWK(I) = ANEWGK(I)
      GO TO 100
C
C     OPTION THAT MAKES NO CHANGES IN POSITIVE INCREMENTS WHEN SUMNEG IS LES
C     THAN 1. X E -8
C
  213 DO 214  I=1,NKK
  214 GWK(I) = ANEWGK(I)
      GO TO 100
C
C     WRITE MAXIMUM RESPONSE VALUE
C
```

```
   47  WRITE(6,120)GAMX,VAMX,DMAX
  120 FORMAT('1'//10X,'MAXIMUM GROUND ACCELERATION = ',F6.3,' G''S'//
     $10X,'MAXIMUM GROUND VELOCITY = ',F6.3,' IN./SEC.'//
     $10X,'MAXIMUM GROUND DISPLACEMENT   ',F6.3,' IN.'//
     $20X,'SIMULATED GROUND ACCELERATION'//)
      DO 17 I=1,NACCG
   17 ACCG(I)=ACCG(I)/386.4
      WRITE(6,5203) (ACCG(I),I=1,NACCG)
 5203 FORMAT (5H     ,15F8.4)
      IF (IPCH.EQ.0) GO TO 36
      WRITE(7,4111) (ACCG(I),I=1,NACCG)
 4111 FORMAT(8F9.5)
      KOUNT=0
      JK=0
      WRITE (7,1) TITLE
      WRITE (7,22) NDAMP,NKK
   22 FORMAT (2I10)
      WRITE (7,13) (TQ(I),I=1,NKK)
   13 FORMAT (10F8.4)
 9101 KOUNT=KOUNT+1
      J=JK+1
      JK=JK+8
      IF (JK.LT.NACCG) GO TO 9103
      JJ=NACCG+1
      DO 9104 K=JJ,JK
 9104 ACCG(K)=0.0
 9103 WRITE (7,301) (ACCG(I), I=J,JK),KOUNT
  301 FORMAT (8F9.5,I8)
      IF (JK.LT.NACCG) GO TO 9101
      TEMP=99.
      KOUNT=KOUNT+1
      WRITE (7,9102) TEMP,KOUNT
 9102 FORMAT (F9.6,63X,I8)
   36 CONTINUE
      DO 9012 LL=1,NDAMP
      WRITE (6,4535) AMOR(LL)
 4535 FORMAT (1H1,' DAMPING =',F6.3///, 9X,'PERIOD',6X,'FREQUENCY',
     1        7X,'RESPONSE',6X,'TIME'//)
      IF (IPCH.EQ.0) GO TO 37
      CAM=AMOR(LL) * 100.
      WRITE (7,9016) CAM
 9016 FORMAT ('DAMPING  ',F4.1,'  PER CENT')
      WRITE (7,888) (PLTVMX(LL,N),N=1,NKK)
 9015 FORMAT(10F8.4)
   37 CONTINUE
 9012 WRITE (6,4340) ((TQ(KK),FRQ(KK),PLTVMX(LL,KK),TMD(LL,KK),KK),
     $     KK=1,NKK)
      IF (NRES.EQ.0) GO TO 100
      WRITE(6,9567)
      DO 23 I=1,NKK
      AMULT=SV(I)/PLTVMX(1,I)
      RATIOS = ABS (1./AMULT)*100.
      PERCEN(I) =       RATIOS - 100.
   23 WRITE(6,8901) TQ(I),FRQ(I),GWK(NKK-I+1),SV(I),PLTVMX(1,I),
     * PERCEN(I),TMD(1,I),I
 4340 FORMAT(' ',4F14.4,I10)
      DO 21 II=1,NDAMP
      DO 21 JJ=1,NKK
   21 PLTVMX(II,JJ)=ABS(PLTVMX(II,JJ))
      NFC=2
```

```
      DO 1000 II=1,NDAMP
      DO 1001 J=1,NKK
 1001 SI(J)=PLTVMX(II,J)
      XAMOR=AMOR(II)
      CALL DIR2 (NFC,4,1,0,NKK,TS,TL,VMIN,VMAX,1.,1.,0,0,0,0,-2,-2,
     8TO,SI,SV,TIX,TITX,TITY,36,36,36,0,0,,XAMOR)
 1000 CONTINUE
  100 CONTINUE
  505 CONTINUE
      IF(NKK.GT.0)GOTO1100
 1100 CALL PLTND(KIKI)
      CALL EXIT
      END
      SUBROUTINE DUMMY(W,FOUT,NKK,WB,GWK,MM)
      DIMENSION WB(1),GWK(1)
      JAY=MM
    1 IF(W-WB(JAY)) 5,4,2
    2 JAY=JAY+1
      IF (JAY.LE.NKK) GO TO 1
      FOUT=GWK(NKK)
      GO TO 6
    4 FOUT=GWK(JAY)
      MM=JAY
      GO TO 6
    5 MM=JAY-1
      IF (MM.LE.0) GO TO 4
      SLOPE=(GWK(JAY)-GWK(JAY-1))/(WB(JAY)-WB(JAY-1))
      FOUT=GWK(JAY-1)+SLOPE*(W-WB(JAY-1))
    6 CONTINUE
      RETURN
      END
      SUBROUTINE SPECT (VMAX,TA,GA,N,DEL,PD,IP,DMP,ID)
C
C  SUBROUTINE FOR COMPUTATION OF SPECTRA FROM EARTHQUAKE RECORD
C  DIGITIZED AT EQUAL TIME INTERVALS
C
      DIMENSION VMAX(10,300),TA(10,300),GA(8001),PD(300),DMP(10),
     1          A(2,2),B(2,2),TY(3),X(3),G(2)
      DO 6 J=1,ID
      D=DMP(J)
      DO 6  K=1,IP
      P=PD(K)
      IF (P.LT.0.001) P=0.001
      W=6.2831856/P
C
C  CHOICE OF INTERVAL OF INTEGRATION
C
      DELP=P/10.
      L=DEL/DELP+1.-1.E-5
      DELT=DEL/L
C
C  COMPUTATION OF MATRICES A AND B
C
      CALL PCN04(D,W,DELT,A,B)
C
C  INITIATION
C
      X(1)=0.
      X(2)=0.
      DMAX=0.
```

```
      I=1
      DW=2.*W*D
      W2=W**2
      IA=2.*P/DELT+1.E-05
C
C  COMPUTATION OF RESPONSE
C
      L1=0
    1 SL=(GA(I+1)-GA(I))/ L
      DO 5 M=1,L
      G(1)= GA(I)+SL*(M-1)
      G(2)= GA(I)+SL*M
      TY(1)=A(1,1)*X(1)+A(1,2)*X(2)-B(1,1)*G(1)-B(1,2)*G(2)
      TY(2)=A(2,1)*X(1)+A(2,2)*X(2)-B(2,1)*G(1)-B(2,2)*G(2)
      L1=L1+1
      TIME=(L1-1)*DELT
C
C  MONITORING THE MAX. VALUES
C
      IF (ABS(TY(1)).LE.ABS(DMAX)) GO TO 2
      DMAX=TY(1)
      TD=TIME
    2 X(1)=TY(1)
    5 X(2)=TY(2)
C
C  TEST FOR END OF INTEGRATION
C
      I=I+1
      IF (I.EQ.N) GO TO 7
      GO TO 8
    7 VEND=X(2)
    8 IF (I.EQ.(N+IA)) GO TO 10
      IF (I.GE.N) GO TO 9
      GO TO 1
    9 GA(I+1)=0.
      GO TO 1
   10 CONTINUE
      VMAX(J,K)=W*DMAX
      TA(J,K)=TD
    6 CONTINUE
      RETURN
      END
      SUBROUTINE DIB2 (NFC,IND,NGRAPH,NGD,NPOINT,XL,XR,YB,YT,DX,DY,
     $N,M,I,J,NX,NY,K,Y,Z,TIT,TITX,TITY,NT,NTX,NTY,NPT,PTMRK,XAMOR)
      DIMENSION X(1),Y(1),Z(1),TIT(1),TITX(1),TITY(1),PTMRK(1)
      INDA=0
      GO TO (1,2,3,4),IND
    1 CALL SMXYV(0,0)
      GO TO 5
    2 CALL SMXYV(0,1)
      GO TO 5
    3 CALL SMXYV(1,0)
      GO TO 5
    4 CALL SMXYV(1,1)
    5 CONTINUE
      CALL SETMIV(150,100,150,150)
      IF(NFC-1) 11,10,20
   10 NFA=2
      GO TO 30
   20 NFA=4
```

```
 30 CALL GRIDIV(NFA,XL,XR,YB,YT,DX,DY,N,M,I,J,NX,NY)
    CALL RITE2V(125,250,1000,90,2,NTY,1,TITY,NLAST)
    CALL RITE2V(300,125,1000,0,2,NTX,1,TITX,NLAST)
    CALL RITE2V(250,925,1000,0,2,NT,1,TIT,NLAST)
    CALL LABLV (XAMOR,750,RRO,6,1,1)
 11 CALL INCRV(B,4)
    NAU=NGRAPH+NGD
    IF(NAU) 401,401,400
400 DO 7 II=1,NAU
    NAUX=NPOINT-1
    DO 8 K=1,NAUX
    IAUX=(II-1)*NPOINT+K
    X1=X(K)
    Z1=Z(K)
    X2=X(K+1)
    Z2=Z(K+1)
    Y1=Y(IAUX)
    Y2=Y(IAUX+1)
    IF(Y1-YT) 100,100,101
100 IF(Y2-YT) 110,110,103
103 X2=(X2-X1)*(YT-Y1)/(Y2-Y1)+X1
    Y2=YT
    GO TO 110
101 IF(Y2-YT) 104,104,105
104 X1=(X2-X1)*(YT-Y1)/(Y2-Y1)+X1
    Y1=YT
    GO TO 110
105 INDA=1
110 CONTINUE
    IF(Y1-YB) 200,201,201
200 IF(Y2-YB) 205,203,203
205 INDA=1
    GO TO 210
203 X1=(X2-X1)*(YB-Y1)/(Y2-Y1)+X1
    Y1=YB
    GO TO 210
201 IF(Y2-YB) 204,210,210
204 X2=(X2-X1)*(YB-Y1)/(Y2-Y1)+X1
    Y2=YB
210 CONTINUE
    IF(INDA) 303,303,302
303 IF(II-NGRAPH) 300,300,301
300 CALL LINEV(NXV(X1),NYV(Y1),NXV(X2),NYV(Y2))
    CALL LINEV(NXV(X1),NYV(Y1),NXV(X2),NYV(Y2))
    CALL DOTLNV (NXV(X1),NYV(Z1),NXV(X2),NYV(Z2))
    GO TO 302
301 CALL DOTLNV(NXV(X1),NYV(Y1),NXV(X2),NYV(Y2))
    CALL DOTLNV(NXV(X1),NYV(Y1),NXV(X2),NYV(Y2))
302 INDA=0
  8 CONTINUE
  7 CONTINUE
401 IF(NPT) 402,402,403
403 LL=NPOINT*NPT
    DO 500 I=1,NPOINT
    CALL APLOTV(LL,X(I),Y(I),0,NPOINT,NPT,PTMRK,IERR)
500 CALL APLOTV(LL,X(I),Y(I),0,NPOINT,NPT,PTMRK,IERR)
402 RETURN
    END
    SUBROUTINE PCN04(D,W,DELT,A,B)
C
```

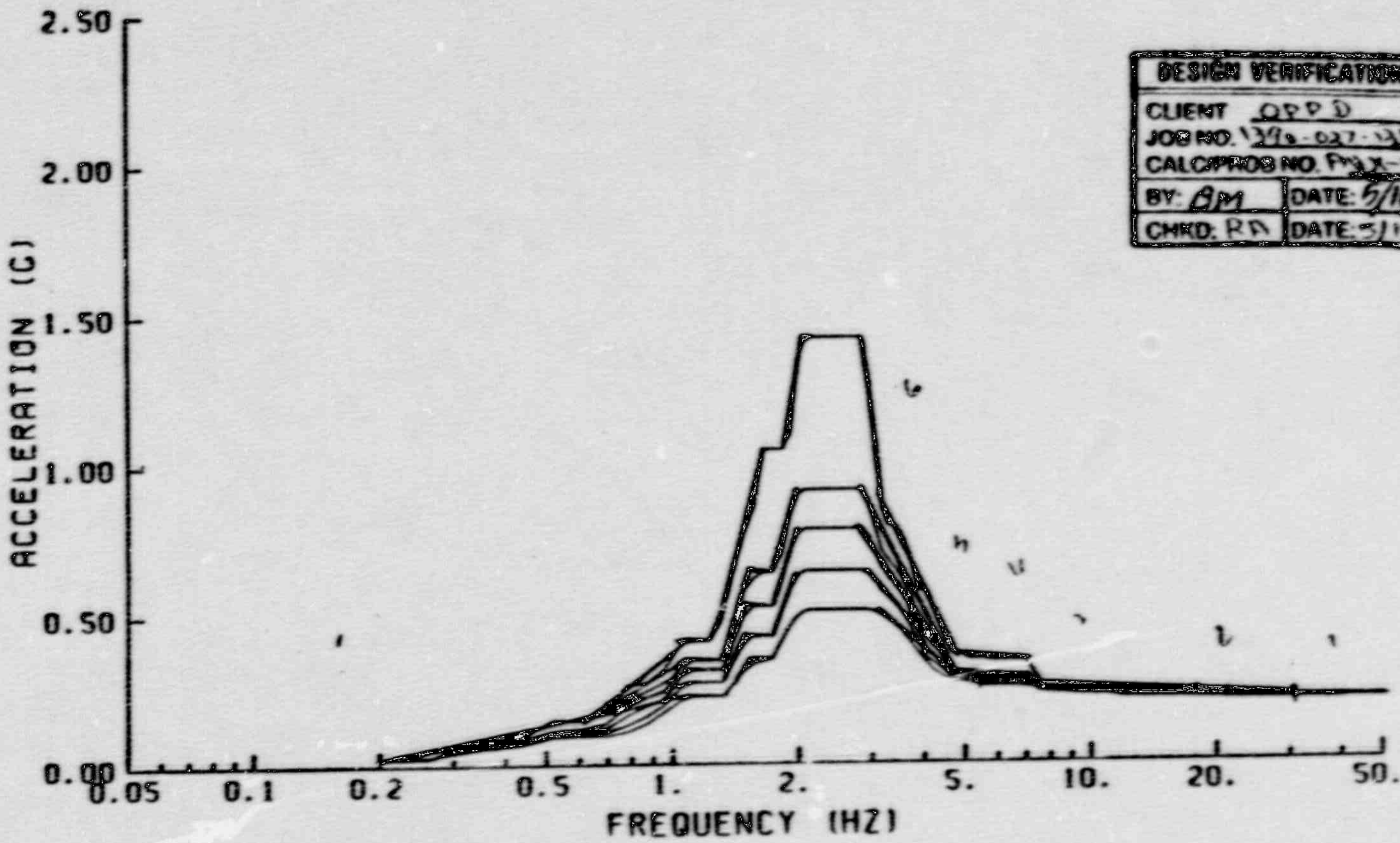
```
C   SUBROUTINE FOR COMPUTATION OF MATRICES A AND B
C
      DIMENSION A(2,2),B(2,2)
      DW=D*W
      D2=D**2
      A0=EXP(-DW*DELT)
      A1=W*SQRT(1.-D2)
      AD1=A1*DELT
      A2=SIN(AD1)
      A3=COS(AD1)
      W2=W**2
      A4=(2.*D2-1.)/W2
      A5=D/W
      A6=2.*A5/W2
      A7=1./W2
      A8=(A1*A3-DW*A2)*A0
      A9=-(A1*A2+DW*A3)*A0
      A10=A8/A1
      A11=A0/A1
      A12=A11*A2
      A13=A0*A3
      A14=A10*A4
      A15=A12*A4
      A16=A6*A13
      A17=A9*A6
      A(1,1)=A0*(DW*A2/A1+A3)
      A(1,2)=A12
      A(2,1)=A10*DW+A9
      A(2,2)=A10
      B(1,1)=(-A15-A16+A6)/DELT-A12*A5-A7*A13
      B(1,2)=(A15+A16-A6)/DELT+A7
      B(2,1)=(-A14-A17-A7)/DELT-A10*A5-A9*A7
      B(2,2)=(A14+A17+A7)/DELT
      RETURN
      END
      SUBROUTINE DUMMX(W,FOUT,NKK,WB,GWK,MM)
      DIMENSION WB(1),GWK(1)
      JAY=MM
    1 IF(W-WB(JAY)) 5,4,2
    2 JAY=JAY+1
      IF (JAY.LE.NKK) GO TO 1
      FOUT=GWK(NKK)
      GO TO 6
    4 FOUT=GWK(JAY)
      MM=JAY
      GO TO 6
    5 MM=JAY-1
      IF (MM.LE.0) GO TO 4
      X=(WB(JAY)+WB(JAY-1))/2.
      IF(W-X) 7,7,8
    7 FOUT=GWK(JAY-1)
      GO TO 6
    8 FOUT=GWK(JAY)
    6 CONTINUE
      RETURN
      END
      SUBROUTINE POLATE(N,M,XIN,YIN,XOUT,YOUT)
      DIMENSION XIN(1),YIN(1),XOUT(1),YOUT(1)
       J=1
      IF(XIN(1)-XOUT(1)) 2,2,100
```

```
  2 IF(XIN(N)-XOUT(M)) 100,3,3
  3 DO 30 I=1,M
  6 IF(XOUT(I)-XIN(J)) 5,40,6
  4 J=J+1
    GO TO 6
  5 J=J-1
    YTEST=(ALOG(YIN(J+1))-ALOG(YIN(J)))*(ALOG(XOUT(I))-ALOG(XIN(J)))/
   $(ALOG(XIN(J+1))-ALOG(XIN(J)))+ALOG(YIN(J))
    YOUT(I)=EXP(YTEST)
    GO TO 30
 40 YOUT(I)=YIN(J)
 30 CONTINUE
    RETURN
100 WRITE(6,20)
 20 FORMAT(1H1,'PROGRAM STOP,FUNCTION UNDEFINED IN DESIRED INTERVAL')
    CALL EXIT
    END
    SUBROUTINE PLTX2(XMIN,XMAX,X,NPOINT)
    DIMENSION X(1)
    POINT=NPOINT-1
    SPACE=ALOG10(XMAX/XMIN)/POINT
    X(1)=XMIN
    DO 1 I=2,NPOINT
    AI=I-1
    EXPO=SPACE*AI
  1 X(I)=XMIN*10.**EXPO
    X(NPOINT)=XMAX
    RETURN
    END
    SUBROUTINE GWPLOT(NKK,TS,TL,GMIN,GMAX,TQ,GW,TITX,TITLO,YTITL)
    DIMENSION TQ(1),GW(1),TITX(1),TITLO(1),YTITL(1)
    IF (GMAX.LE.70.0) GO TO 3
    IF (GMAX.LE.200.0) GO TO 2
    DY=20.0
    GO TO 4
  2 DY=10.0
    GO TO 4
  3 DY=2.0
  4 CONTINUE
C     ESTABLISH SEMILOG COORDINATES
      CALL SMXYV(1,0)
C     ESTABLISH MARGINS
      CALL SETMIV(150,100,150,150)
C     ESTABLISH GRID
      CALL GRID1V(1,TS,TL,GMIN,GMAX,1.0,DY,0,5,0,5,-2,-2)
C     WRITE Y AXIS LABEL
      CALL RITE2V(125,250,1000,90,2,28,1,YTITL,NLAST)
C     WRITE X AXIS LABEL
      CALL RITE2V(300,125,1000,0,2,36,1,TITX,NLAST)
C     WRITE TITLE
      CALL RITE2V(250,925,1000,0,2,28,1,TITLO,NLAST)
C     JOIN POINTS WITH STRAIGHT LINES
      NKKM1=NKK-1
      DO 1 I=1,NKKM1
      X1=TQ(I)
      X2=TQ(I+1)
      II=NKK+1-I
      Y1=GW(II)
      Y2=GW(NKK-I)
      IX1=NX (X1)
```

```
      IY1=NYV(Y1)
      IX2=NXV(X2)
      IY2=NYV(Y2)
      CALL LINEV(IX1,IY1,IX2,IY2)
    1 CONTINUE
      RETURN
      END
      SUBROUTINE SVGW(NKK,W,GW,SV,S,B,WC,Q,P,XLAMO,WCP,QP,RR)
      DIMENSION GW(1),W(1),SV(1),RR(1)
      PI=3.14159
      PI2=6.2831852
      GSUM=0.
      DO 1000 I=1,NKK
      NW=NKK-I+1
      POW=2.*B*W(I)*S
      IF(POW.GT.50.0) GO TO 610
      TRANS=1.-EXP(-POW)
      GO TO 611
  610 TRANS=1.
  611 BS=B/TRANS
      WCYS=W(I)
      QYS=SQRT(4.0*BS/PI)
      XSP=-WCYS*S/(PI2*ALOG(P))
      RSTAR=SQRT(2.*ALOG(2.*XSP))
      ET=-RSTAR*QYS*SQRT(PI/2)
      ARG=2.*XSP*(1.-EXP(E
      RSP=SQRT(2.*ALOG(A
      RR(I)=RSP
      GW(I)=(4.*BS/(W(I)*PI)    (SV(NW)*W(1)/RSP)**2-GSUM)
      IF(GW(I).LE.0.01)GW(I)=0.01
      IF(I.GT.1)GO TO 140
      GSUM=0.5*W(1)*GW(1)
      GO TO 1000
  140 GSUM=GSUM+GW(I)*(W(I)-W(I-1))
 1000 CONTINUE
      WCP=0.0
      QP=0.0
      XLAMO=0.
      XLAM1=0.
      XLAM2=0.
      DO 5 I=2,NKK
      DUMX=(GW(I)+GW(I-1))/2.
      DUMY=W(I)-W(I-1)
      IF(GW(I)-GW(I-1)) 10,15,15
   10 A=GW(I)
      B=GW(I-1)
      WBAR=DUMY*(2.*B+A)/(3.*(A+B))
      WSTAR=W(I)-WBAR
      GO TO 16
   15 A=GW(I-1)
      B=GW(I)
      WBAR=DUMY*(2.*B+A)/(3.*(A+B))
      WSTAR=W(I-1)+WBAR
   16 AREA=DUMX*DUMY
      XLAMO=XLAMO+AREA
      XLAM1=XLAM1+WSTAR*AREA
    5 XLAM2=XLAM2+(WSTAR**2)*AREA
      WCP=SQRT(XLAM2/XLAMO)
      RATIO=(XLAM1**2)/(XLAMO*XLAM2)
      QP=SQRT(1.-RATIO)
```

```
      RETURN
      END
/*
//G.SC4020  DD  DSNAME=&&PLOT,DISP=(NEW,PASS),UNIT=SYSDA,
//  SPACE=(1020,(55,7))
//G.SYSIN  DD  *
SIMULATION OF EARTHQUAKE (OPTION 1) BY SHIH-SHENG PAUL LAI
0.02      3.0       0.02      3.0       .1        500.0
   2  2.0     15.0      20.0      0.0       0.0       0.0       0
0.01      1.0                 1235    3    2    1  200    6    0    0
0.02      0.05      0.1
 .0143    1.0
 .0263    1.9
 .1064    22.
 .2444    75.0
 3.333    95.0
 5.0      60.0
/*
//STEP2 EXEC SC4020,PARM='M11794,P14568,HARDCOPY'
/*
```

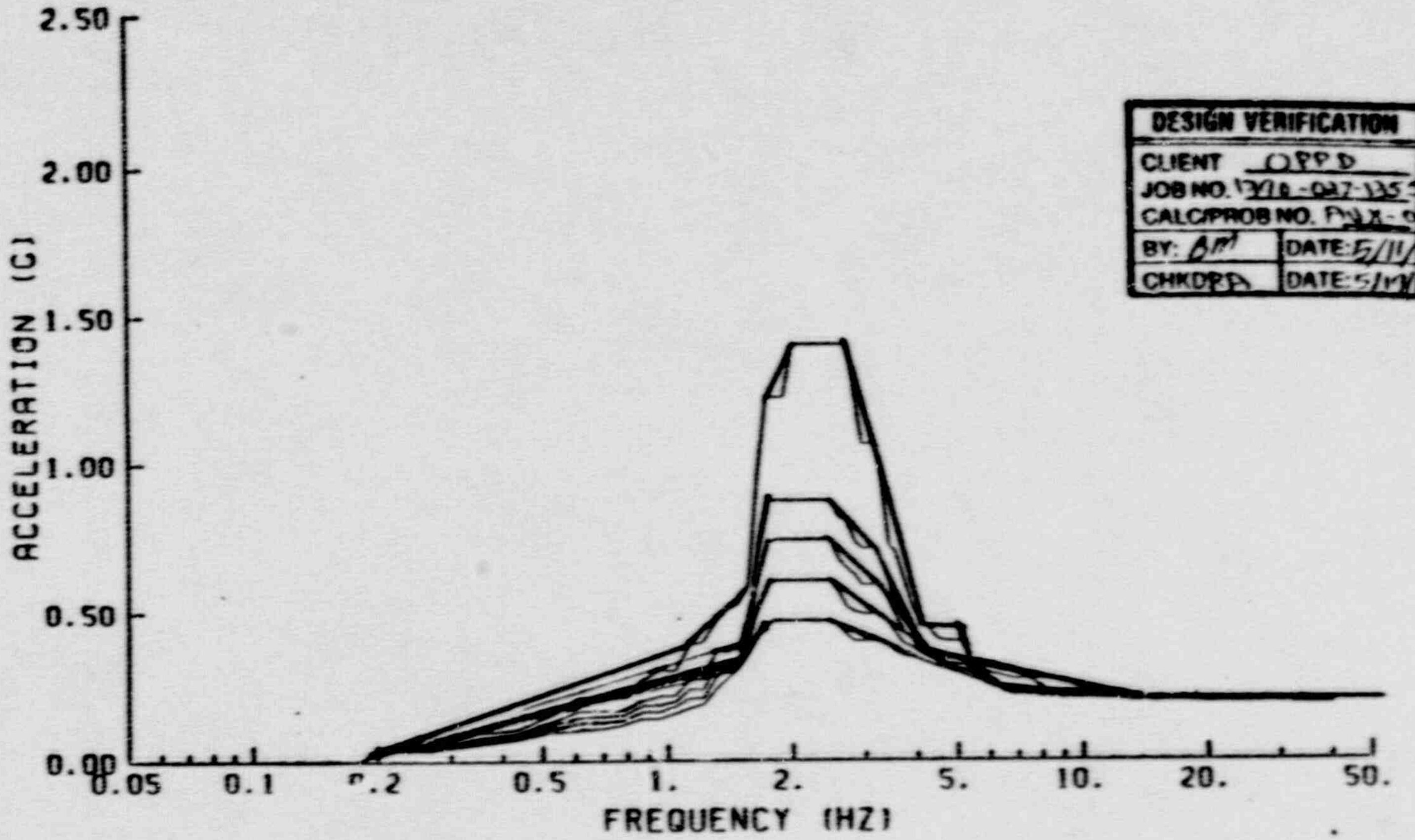
ATTACHMENT 2
IMPELL CALCULATION AUX-31 PAGES 94 TO 103 AND 105 TO 109



DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1355	
CALC/PROB NO. FPX-053	
BY: BM	DATE: 5/11/88
CHKD: RD	DATE: 5/17/88

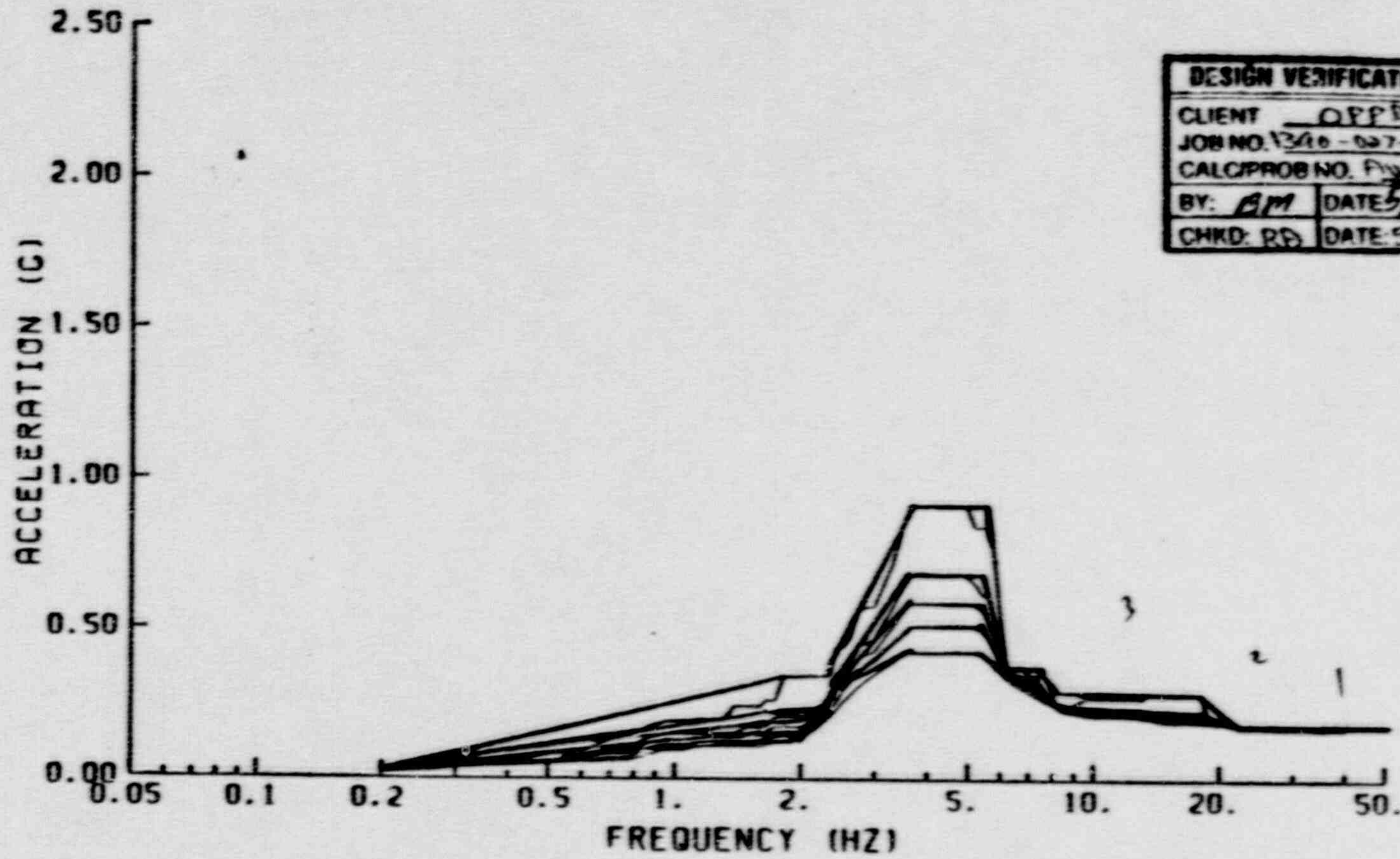
OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING= INTERNAL ST.EL.= 994 FT-0 IN. (CG) DIR.= N-S
DAMPINGS = 2,5,7,10 AND 15 PERCENT

94/146



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING= INTERNAL ST.EL.= 994 FT-0 IN, (CG) DIR.= E-W
DAMPINGS = 2,5,7,10 AND 15 PERCENT

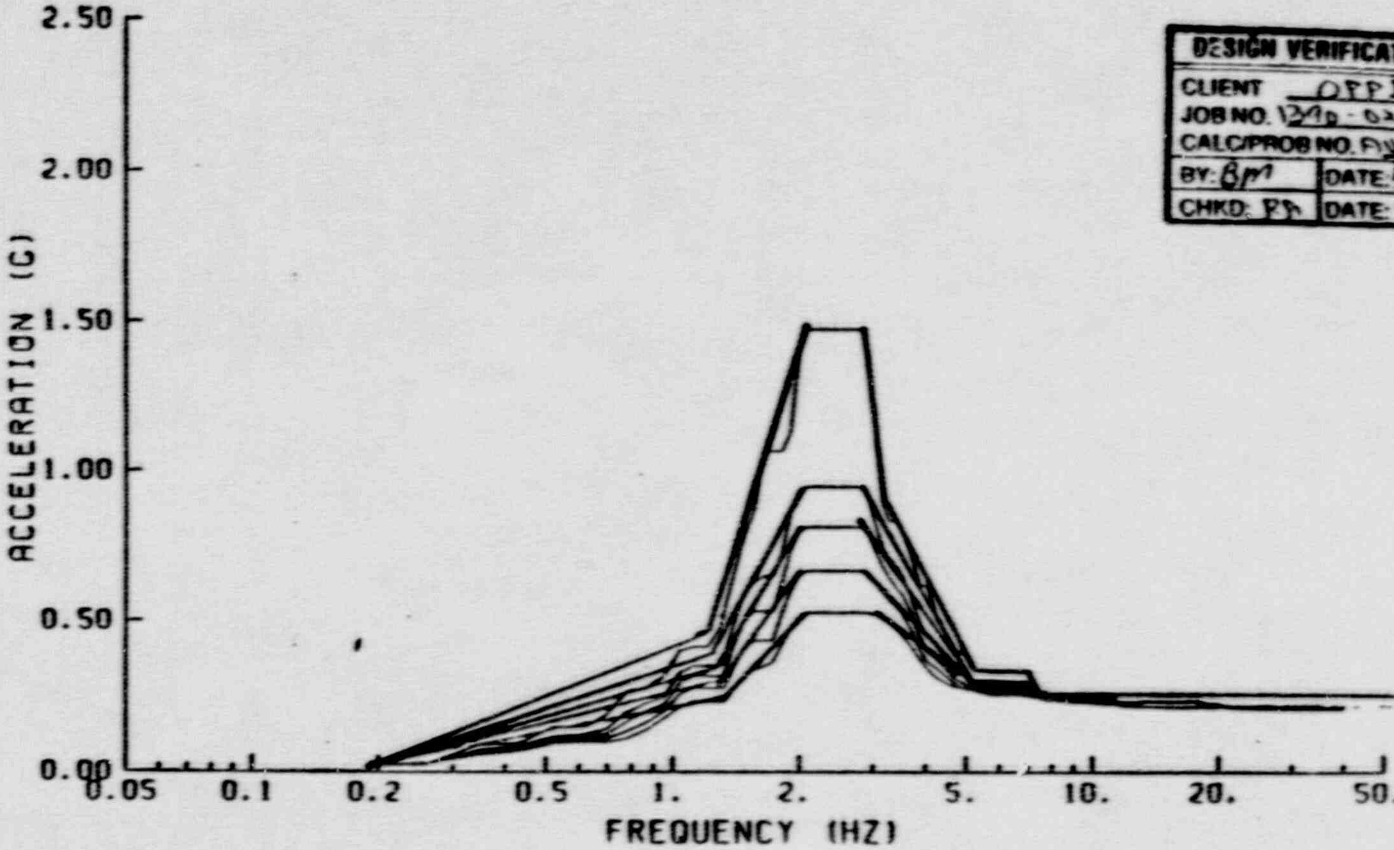
/96



DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1340-007-955	
CALC/PROB NO.	
BY: BM	DATE 5/14/88
CHKD: RD	DATE 5/14/88

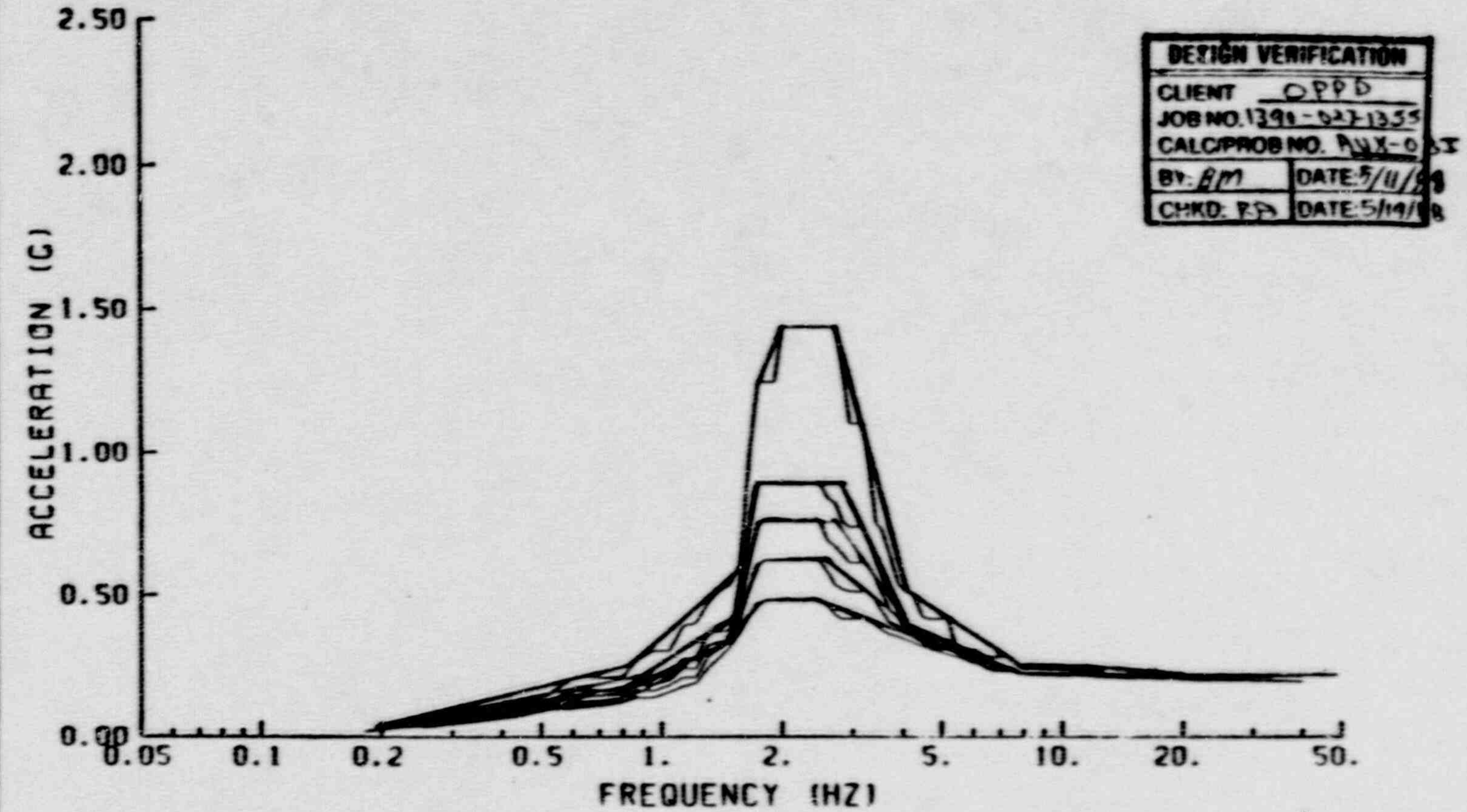
OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING= INTERNAL ST.EL.= 994 FT-0 IN, (CG) DIR.= VER
DAMPINGS = 2,5,7,10 AND 15 PERCENT

/96



DESIGN VERIFICATION
CLIENT OPPD
JOB NO. 1290-027-1355
CALC/PROB NO. FIV-X-0[illegible]
BY: BPM DATE: 5/11/88
CHKD: BR DATE: 5/19/88

OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING= INTERNAL ST.EL.= 1013 FT-0 IN, (CG) DIR.= N-S
DAMPINGS = 2,5,7,10 AND 15 PERCENT



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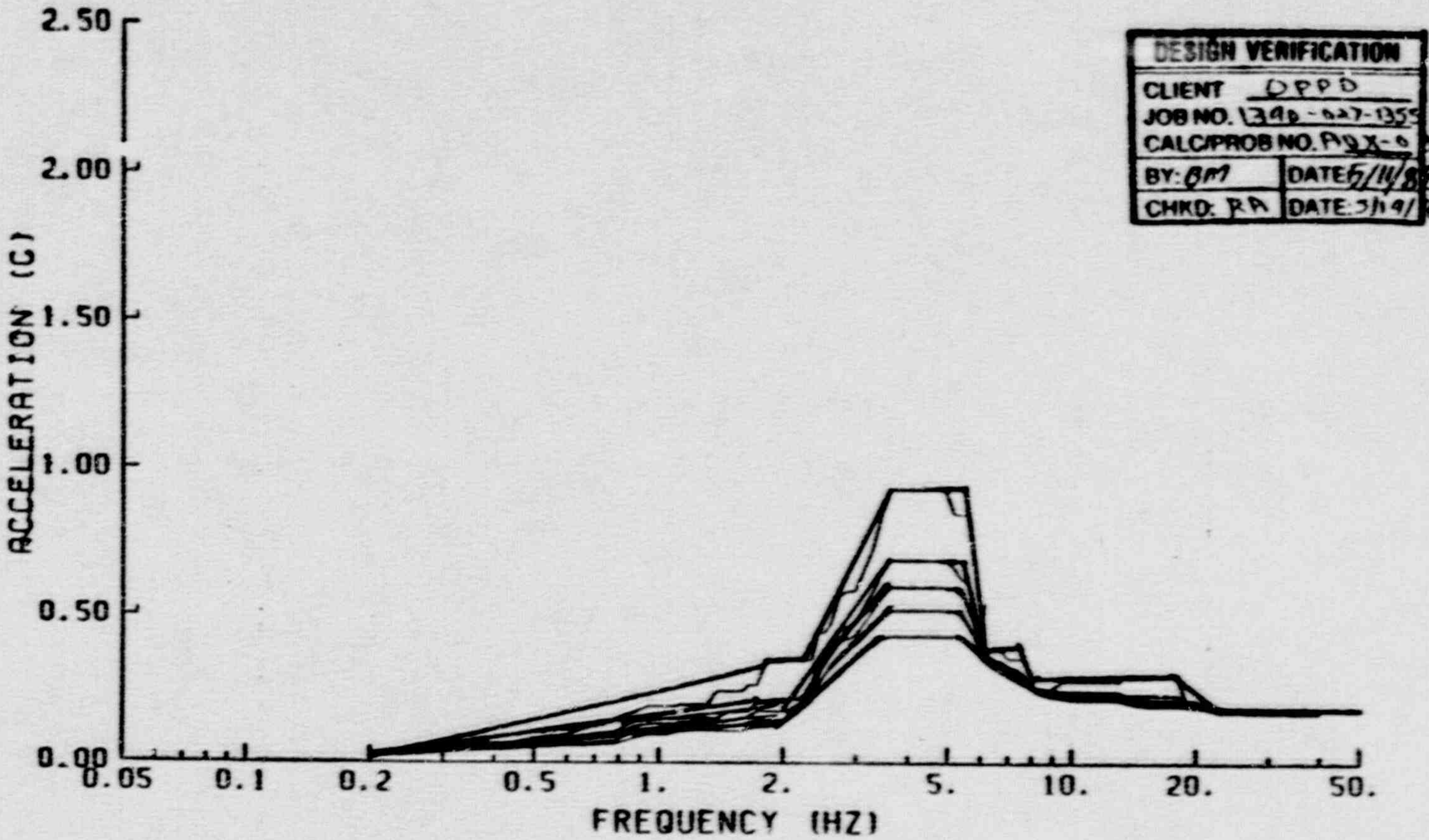
DAMPINGS = 2,5,7,10 AND 15 PERCENT

/86



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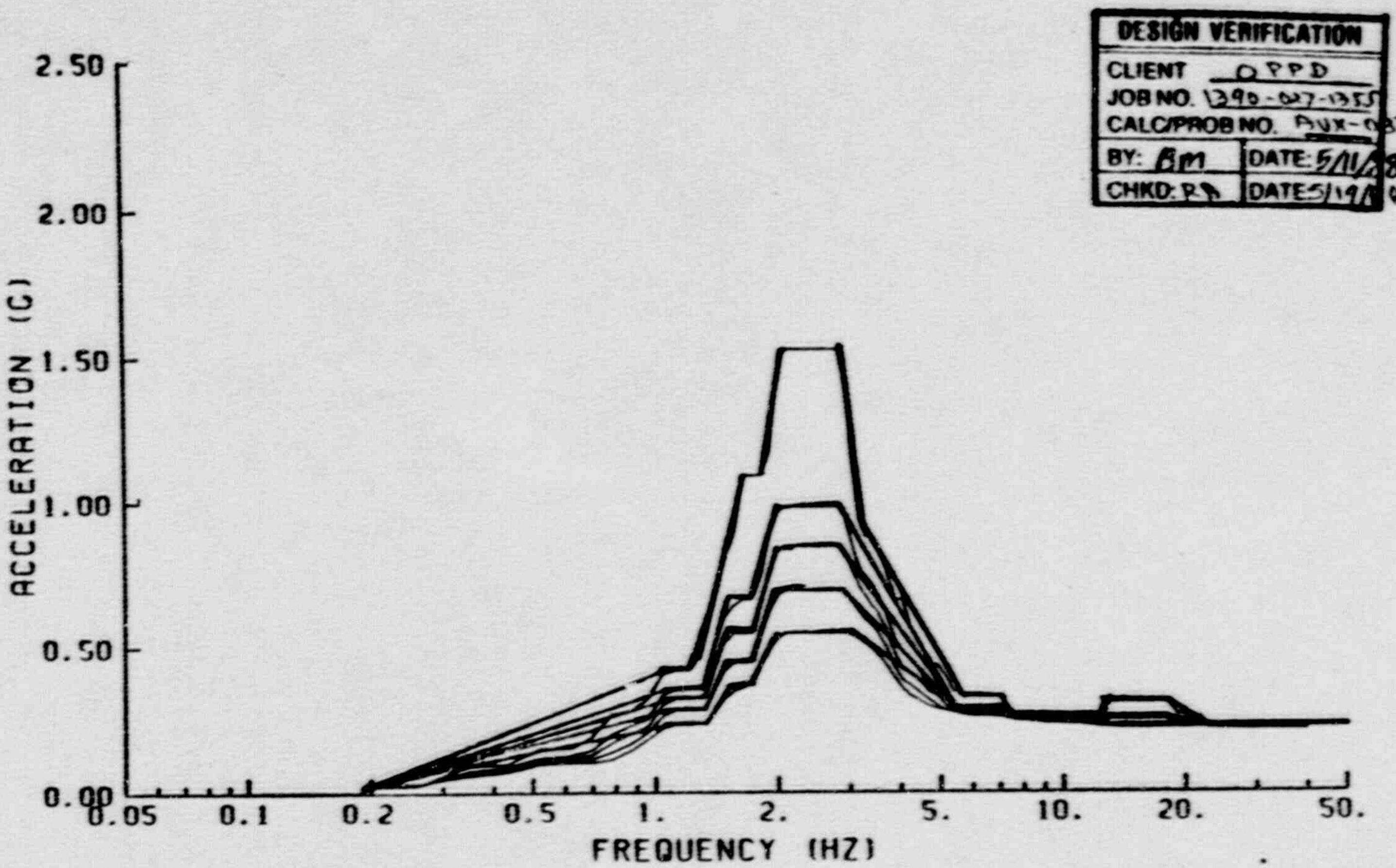

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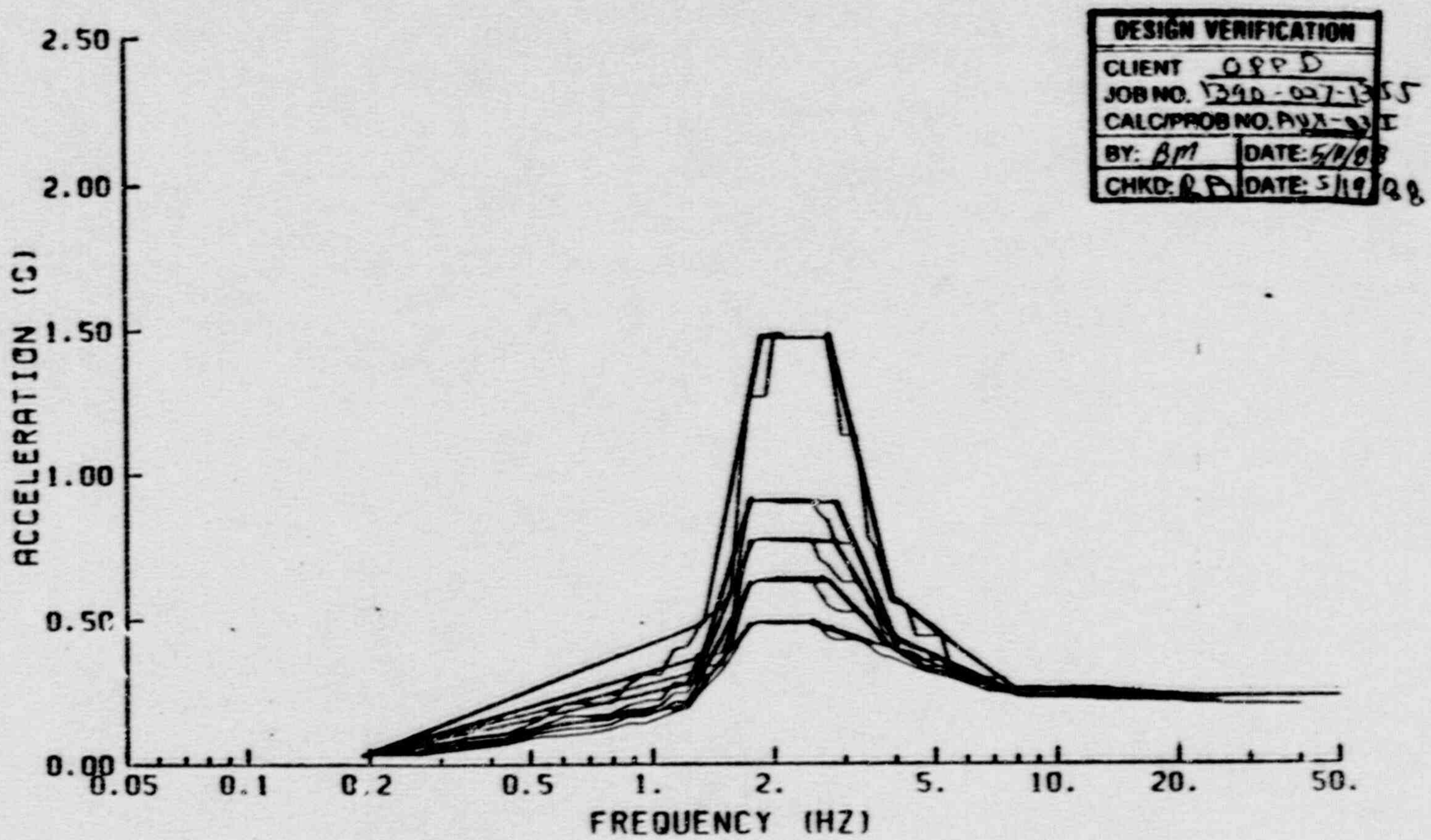
/001



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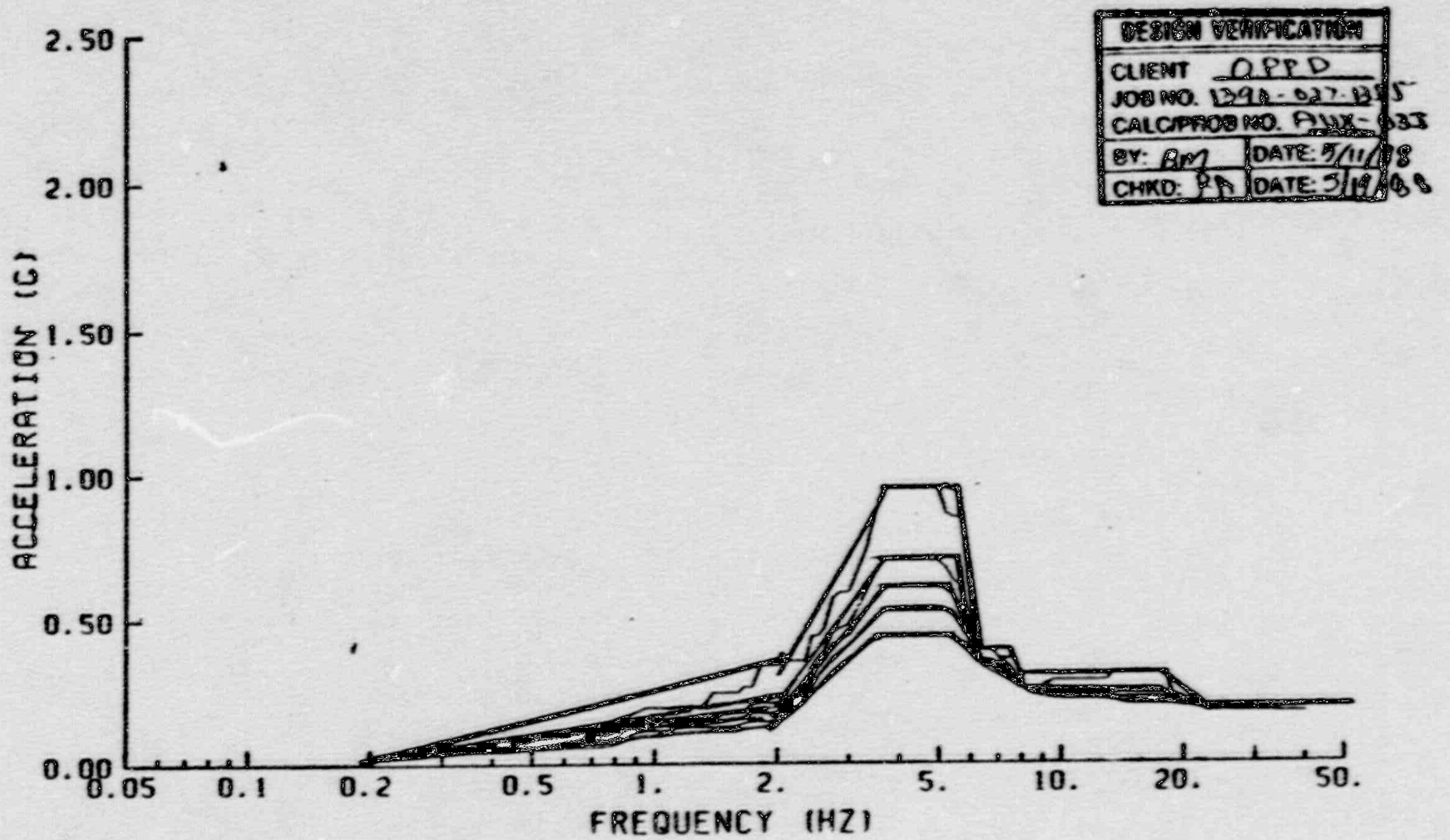
DAMPINGS = 2,5,7,10 AND 15 PERCENT



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DAMPINGS = 2,5,7,10 AND 15 PERCENT

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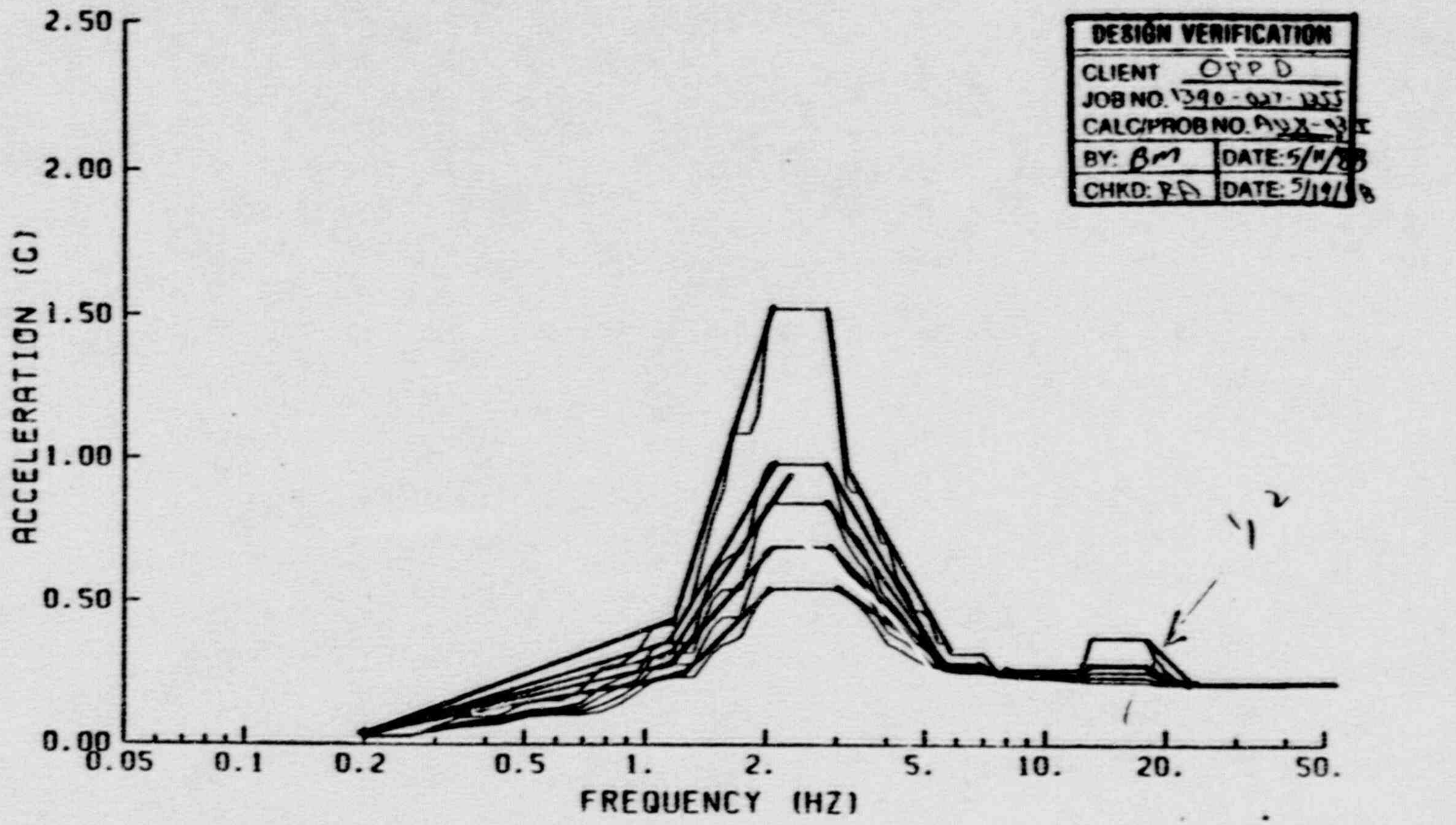

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DAMPINGS = 2, 5, 7, 10 AND 15 PERCENT

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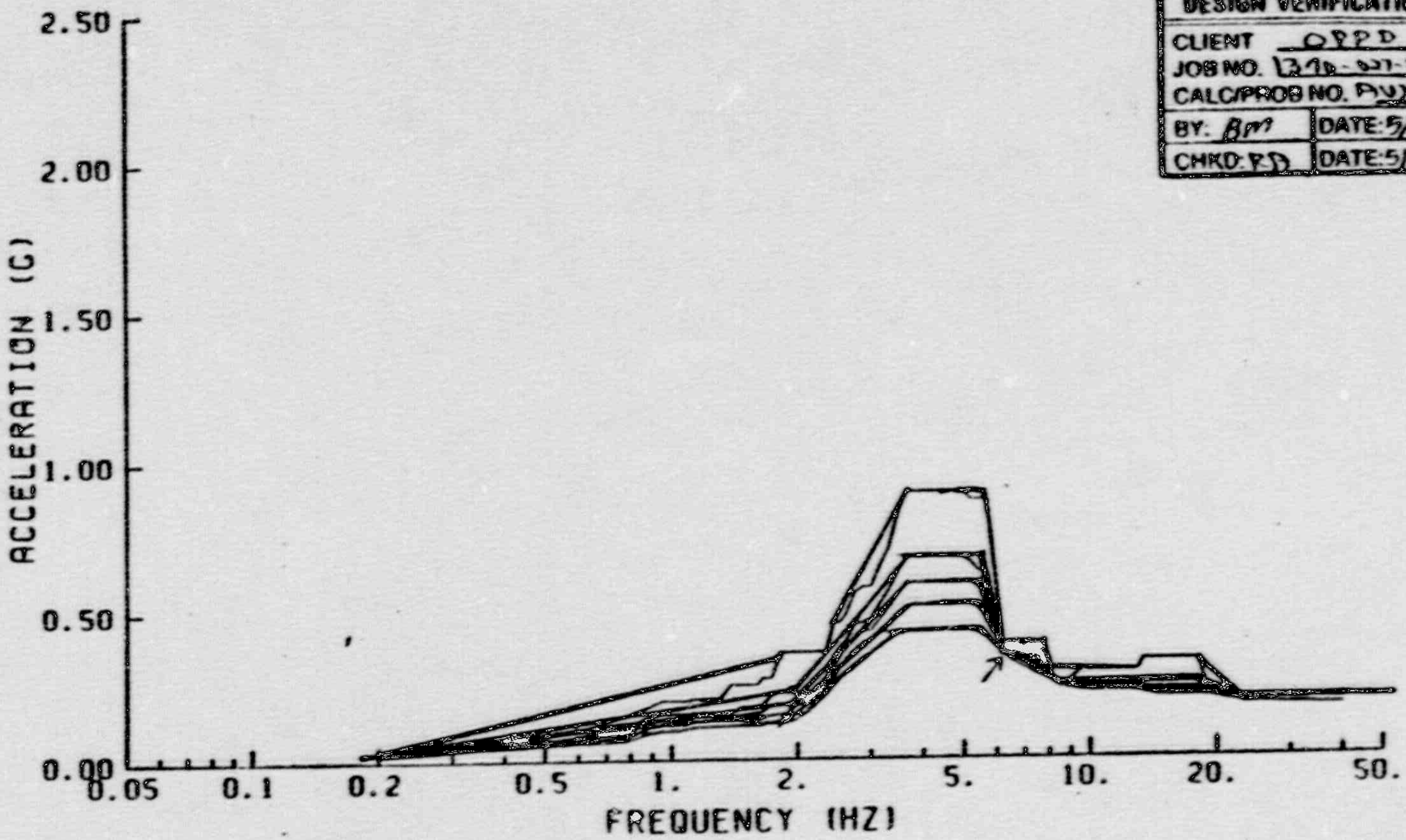

DESIGN VERIFICATION	
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JOB NO. 1376-027-135	
CALC/PROB NO. AUX-03I	
BY: BM	DATE: 5/11/88
CHKD: PD	DATE: 5/19/88

OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
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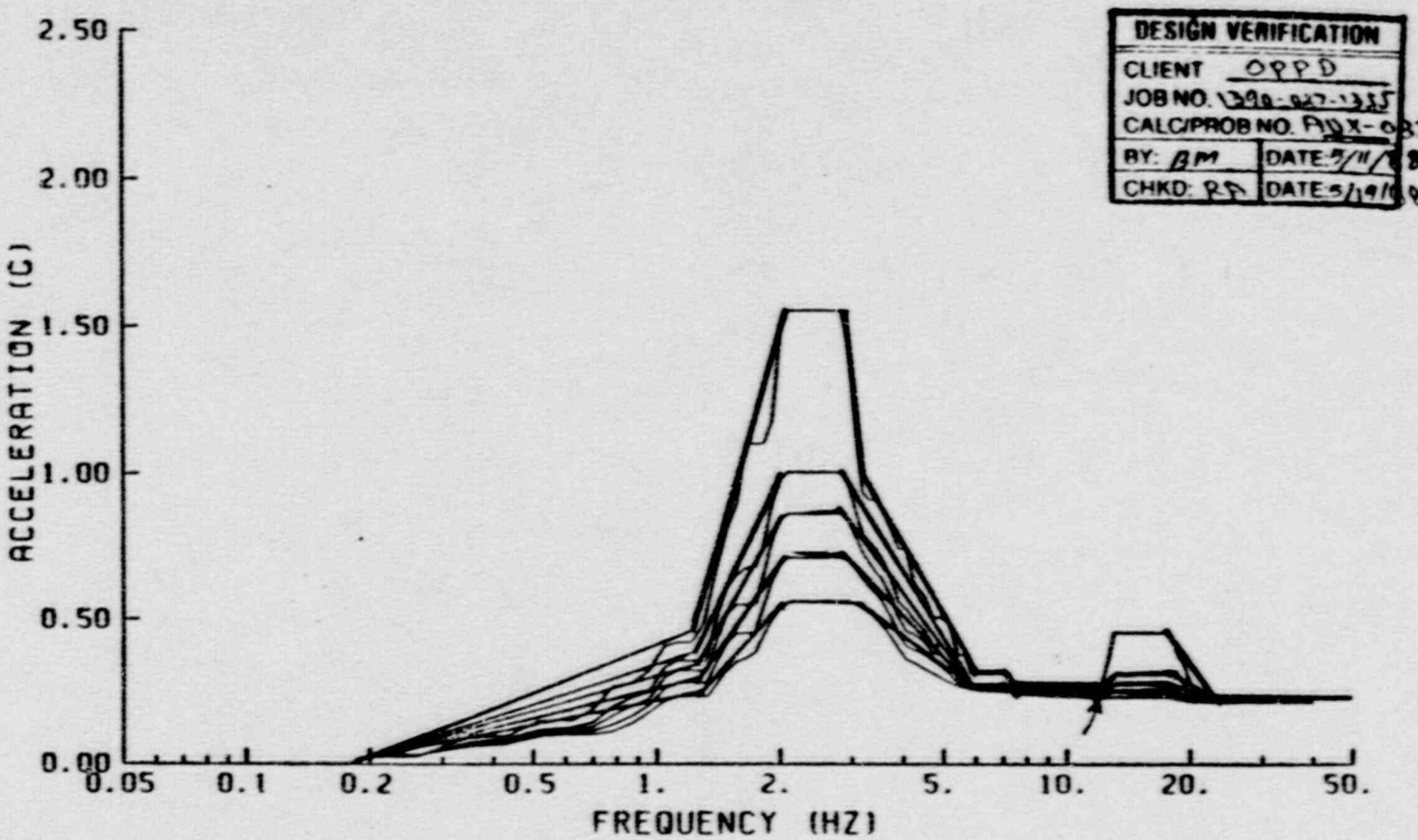
DAMPINGS = 2,5,7,10 AND 15 PERCENT



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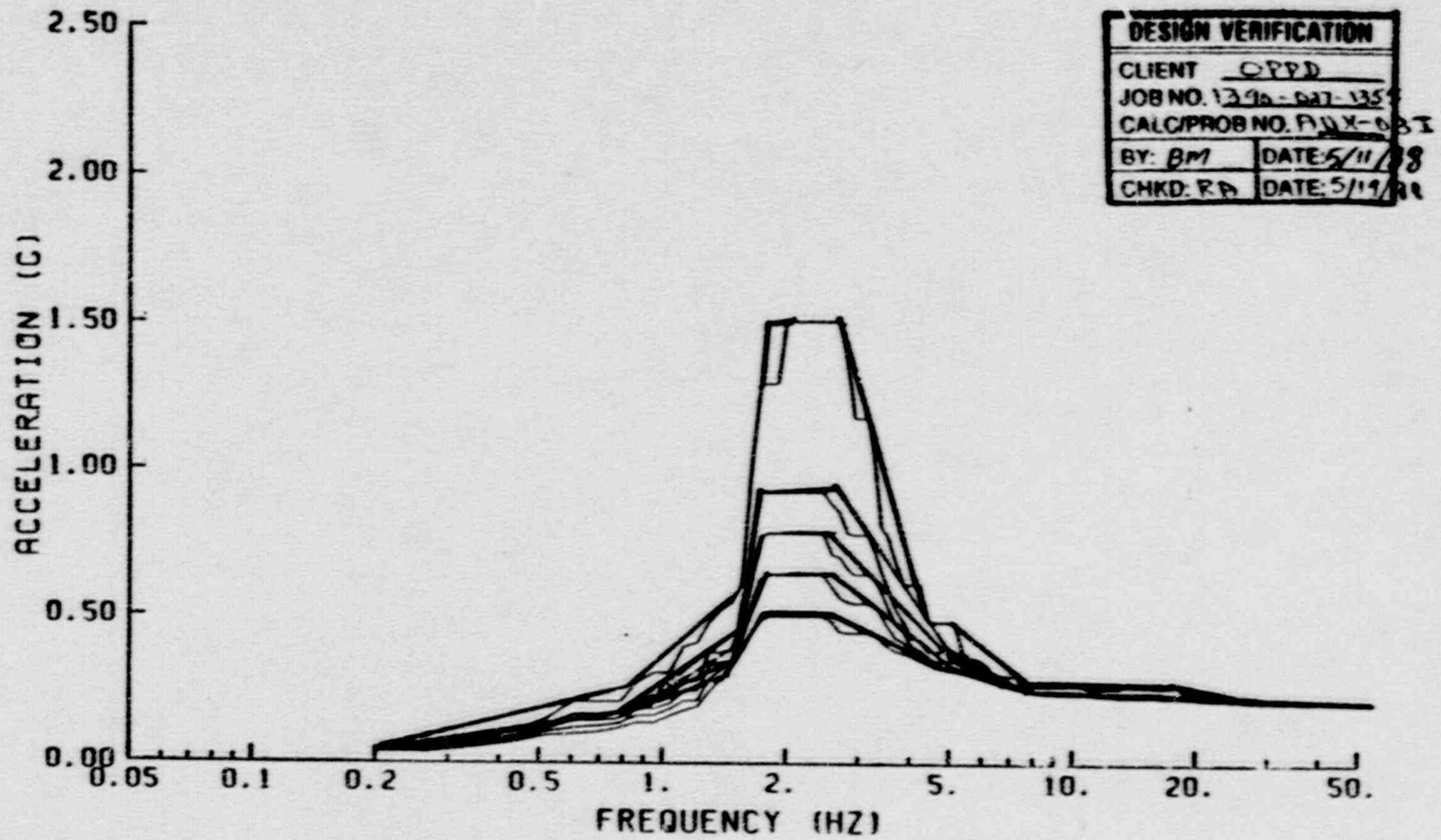
DAMPINGS = 2,5,7,10 AND 15 PERCENT

/901



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING= INTERNAL ST.EL.= 1056 FT-6 IN, (CG) DIR.= E-W
DAMPINGS = 2,5,7,10 AND 15 PERCENT

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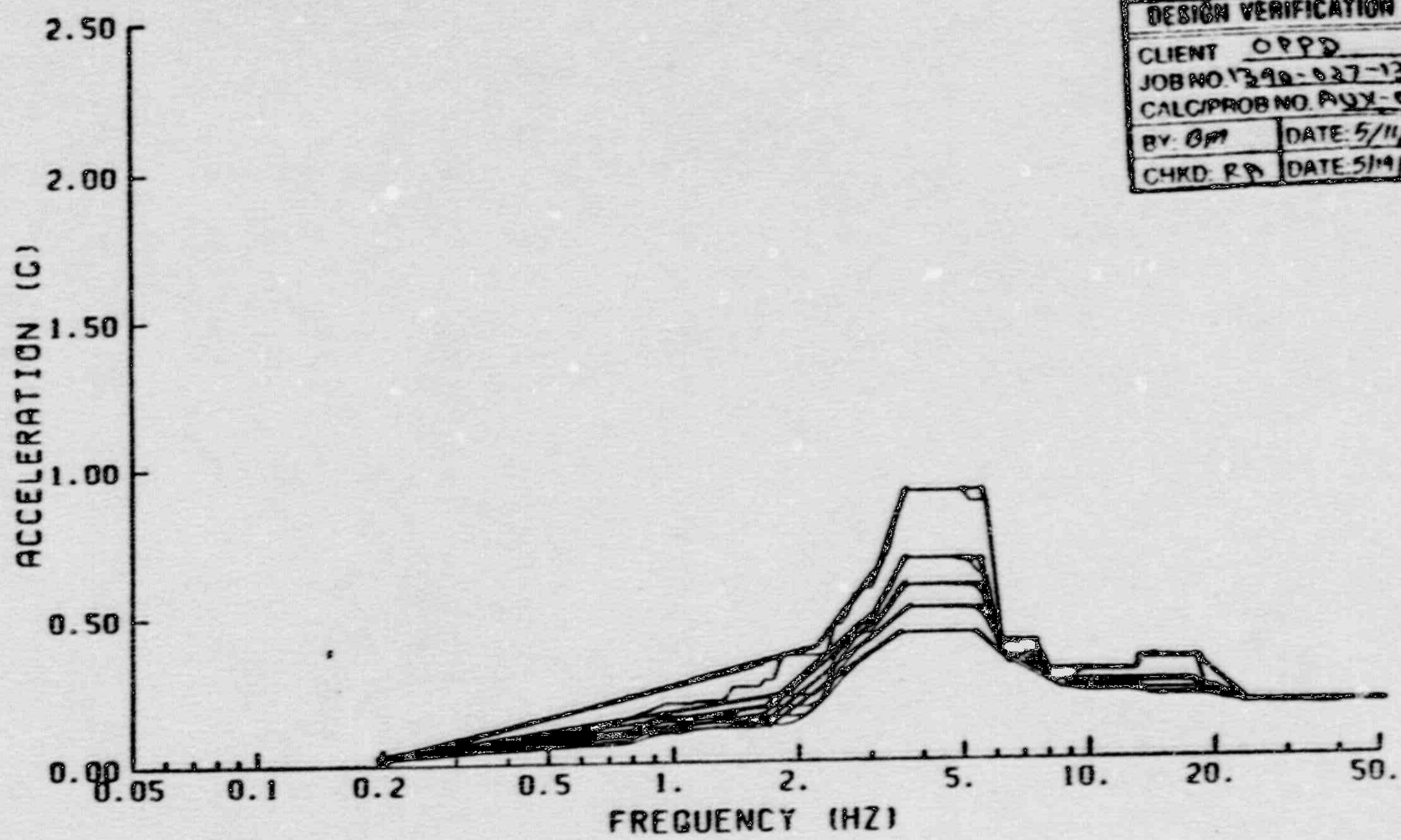

DESIGN VERIFICATION

CLIENT OPPD
JOB NO. 1390-027-1345
CALC/PROB NO. AUX-0
BY: GM DATE: 5/11/88
CHKD: RB DATE: 5/19/88

OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING= INTERNAL ST,EL.= 1056 FT-6 IN. (CC) DIR.= VER
DAMPINGS = 2,5,7,10 AND 15 PERCENT

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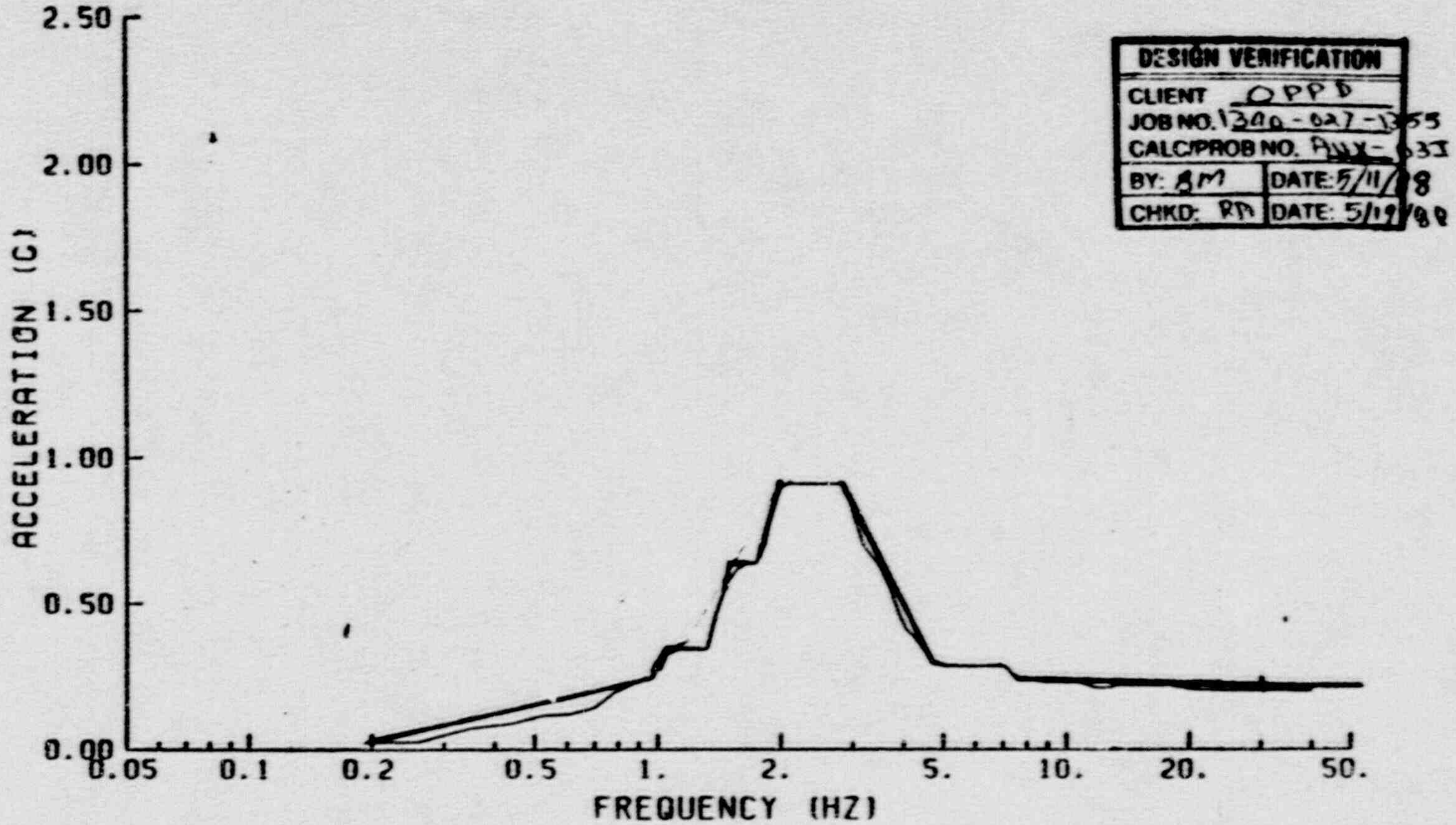

OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING= INTERNAL ST.EL.= 994 FT-0 IN, (CG) DIR.= N-S
DAMPINGS = PVRC

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ATTACHMENT 3
IMPELL CALCULATION No. TURB-02, REV. 0

CALCULATION/PROBLEM COVER SHEET

Calculation/Problem No: JURB-02

Title: SAM For TURBINE BUILDING SSE Event

Client: OPPD **Project:** FORT CALHOUN

Job No: 1390-027-1355

Design Input/References:

Stated Within

Assumptions:

Stated Within

Method:

Stated Within

Remarks:

This Calc. contains page 17a.

Total No. of Pages in the Calc = 98.

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0	Original MICROFILMED	Miguel A. Maunrique	2/3/89
		[illegible] 2-6-89 Q A Concurrence Date	

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					Client OPPD
					Project: Fort Calhoun
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REV	BY	DATE	CHECKED	DATE	

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	2.2. SEISMIC ANCHOR MOVEMENTS	10
	2.2.1. General	10
	2.2.2. Within One Building	11
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3.	FOUNDATION IMPEDANCES	17, including 17a
4	STRUCTURAL MODEL	22
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7	SEISMIC ANCHOR MOVEMENTS WITHIN TURBINE + OFFICE BUILDINGS	67
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APPENDIX A: VERIFICATION OF PROGRAM DISPL	82
Computer Run Log	91
Attachment A	A1-A4

Total No. of pages in Main Body = 94 including 17a

Total Pages in Attachment A = 4

Total Pages in Calc. = 98

Client OPPD

Project: Fort Calhoun

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1 INTRODUCTION

1.1 GENERAL

The structural model for turbine and office buildings at Fort Calhoun, Unit I is developed in Impell Calc. TURB-01 [1]. Acceleration time histories to be used for soil-structure interaction analysis are developed in Calc THG-01 [2]. High strain soil profile, consistent with the acceleration time histories developed in [2], is developed in Impell Calc. SOIL-01 [3].

1.2 PURPOSE

The main purpose of this calc is to calculate seismic anchor movements between Turbine and Auxiliary buildings, and within Turbine building. However, broadenened floor spectra are generated at two elevations to evaluate response of Turbine building. Thus, the tasks to be performed in this calc

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are as follows:

(1) Develop broadened floor spectra at two elevations of turbine building for safe shutdown earthquake (SSE) event.

(2) Calculate seismic anchor movements with Turbine Building.

(3) Calculate seismic anchor movements between Turbine and Auxiliary buildings.

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2 METHODOLOGY

2.1 BROADENED FLOOR SPECTRA

The methodology used to develop broadened floor spectra is shown in Fig 2.1, and is described below.

(1) Calculate normalized foundation impedances using the GLAYER and CLAF module of CLASSI [6].

(2) Calculate response acceleration time histories at appropriate nodes, using SSIN module of CLASSI [6]. Normalized impedances calculated in Step (1) are used as input for SSIN module.

(3) Calculate response spectra for acceleration time histories generated from CLASSI. Use program RESPEC [7].

(4) Envelop response spectra at all locations calculated for a floor in each direction. Broaden the enveloped spectra by 15% [5]. Use

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project specific program BMENV [8] for enveloping, and SPECT1A [9] for broadening the enveloped spectra

(5) Plot the broadened response spectra, using EDSPLOT [10]

Design floor spectra can be obtained from broadened floor spectra by smoothening the broadened spectra as per Reg Guide 1.122 [11]

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GENERATION OF BROADENED RESPONSE SPECTRA

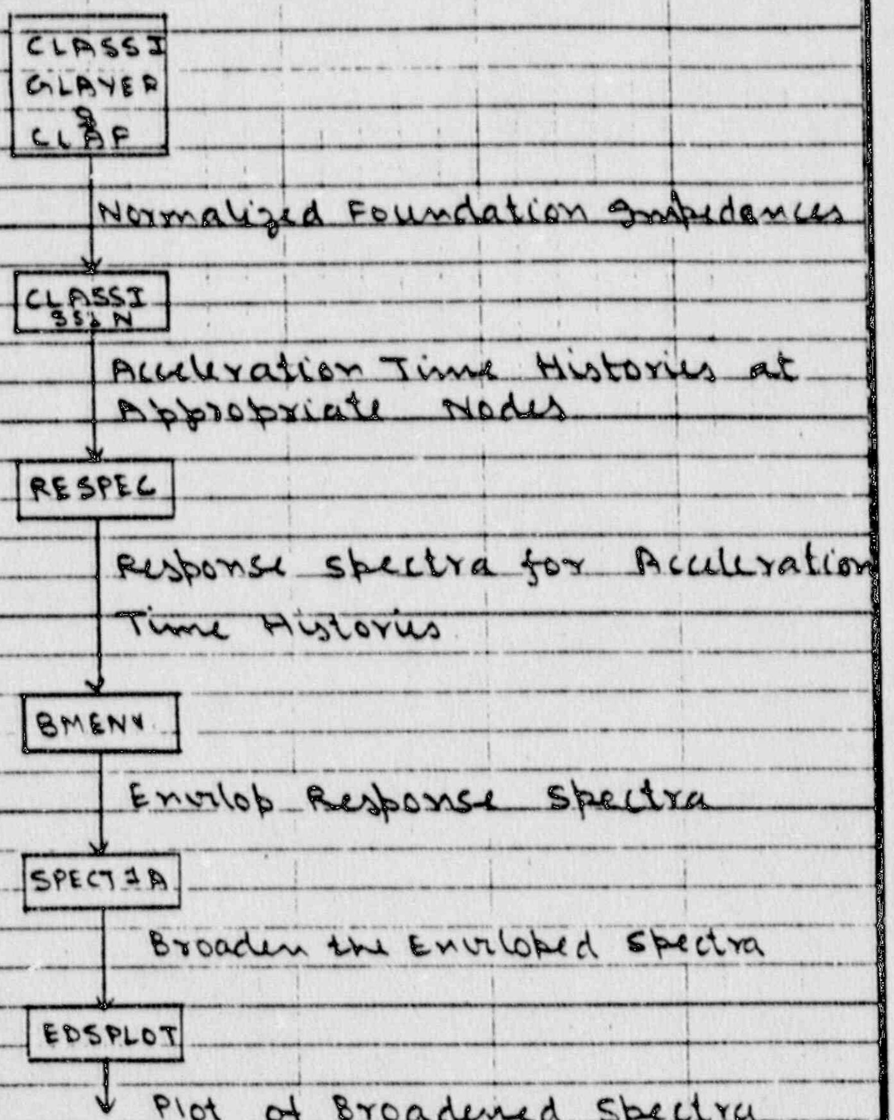

FIG. 2.1 METHODOLOGY FOR BROADENED FLOOR SPECTRA

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2.2 SEISMIC ANCHOR MOVEMENTS

2.2.1 General

Relative displacements between two floors are calculated by subtracting the second floor response acceleration time history from the first floor response acceleration time history, and then double integrating to get relative displacement time history. Project specific program DISPL [15] is used to subtract the two acceleration time histories, and also to do the double integration. Program DISPL also finds the maximum relative displacement.

Absolute displacement at any floor are calculated by double integrating the floor's response acceleration time history, using the program DISPL. Program DISPL also finds maximum absolute displacement.

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Maximum floor relative displacements and absolute displacements are used to calculate seismic Anchor motions, as described below.

2.2.2. Within One Building

Maximum relative displacement of a floor with respect to base, and maximum relative displacement between two consecutive floors (i.e. floor or story drift) are calculated. Procedure to calculate seismic anchor motions (SAM) for equipments or components supported on floors i & j, where j>i, is calculated as follows:

(1) Calculate

$$(S_{ij})_b = |\Delta_{bi}| + |\Delta_{bj}|$$

where

Δ_{bi}, Δ_{bj}: Maximum relative displacement for floor i, j with respect to base

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(2) Calculate

$$(S_{ij})_j = |\Delta_{i,i+1}| + |\Delta_{i+1,i+2}| + \ldots + |\Delta_{j-1,j}|$$

where

$\Delta_{i,i+1}$ = Maximum relative displacement (inter floor drift) between floors i and i+1.

(3) S_{ij} = Seismic Anchor Movement between floors i and j
= Minimum $|(S_{ij})_x, (S_{ij})_y|$

The less conservative value for S_{ij} (SAM) can be obtained by calculating relative displacement between floors i and j, directly by double integrating the relative acceleration time history. However, it may not be necessary, as S_{ij} calculated in step (3), may satisfy the performance criteria.

The methodology is shown in Fig. 2.1

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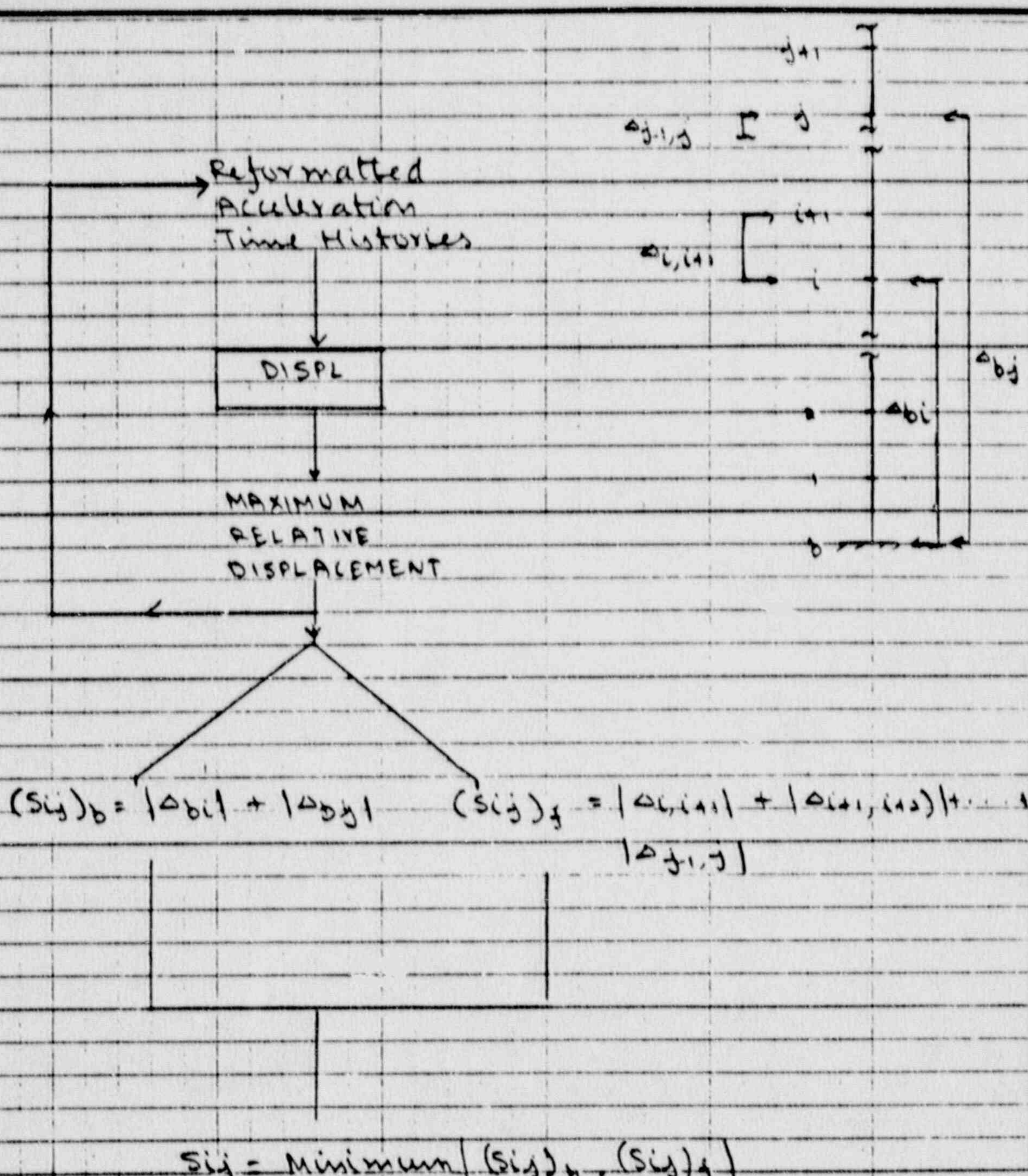

FIG. 2.1 METHODOLOGY FOR SEISMIC ANCHOR MOVEMENT WITHIN ONE BUILDING

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2.2.3 Between Two Buildings

The seismic anchor movement (SAM) between a floor of one building and a floor of another building is calculated as follows

$$S_{i_1 j_2} = |\Delta_{b_1 b_2}| + |\Delta_{b_1 i_1}| + |\Delta_{b_2 j_2}|$$

where

$S_{i_1 j_2}$ = SAM between floor i of building 1 and floor j of building 2.

$\Delta_{b_1 b_2}$ = Maximum relative displacement between base of buildings 1 and 2.

$\Delta_{b_1 i_1}$ = Maximum relative displacement between floor i and base of building 1.

$\Delta_{b_2 j_2}$ = Maximum relative displacement between floor j and base of building 2.

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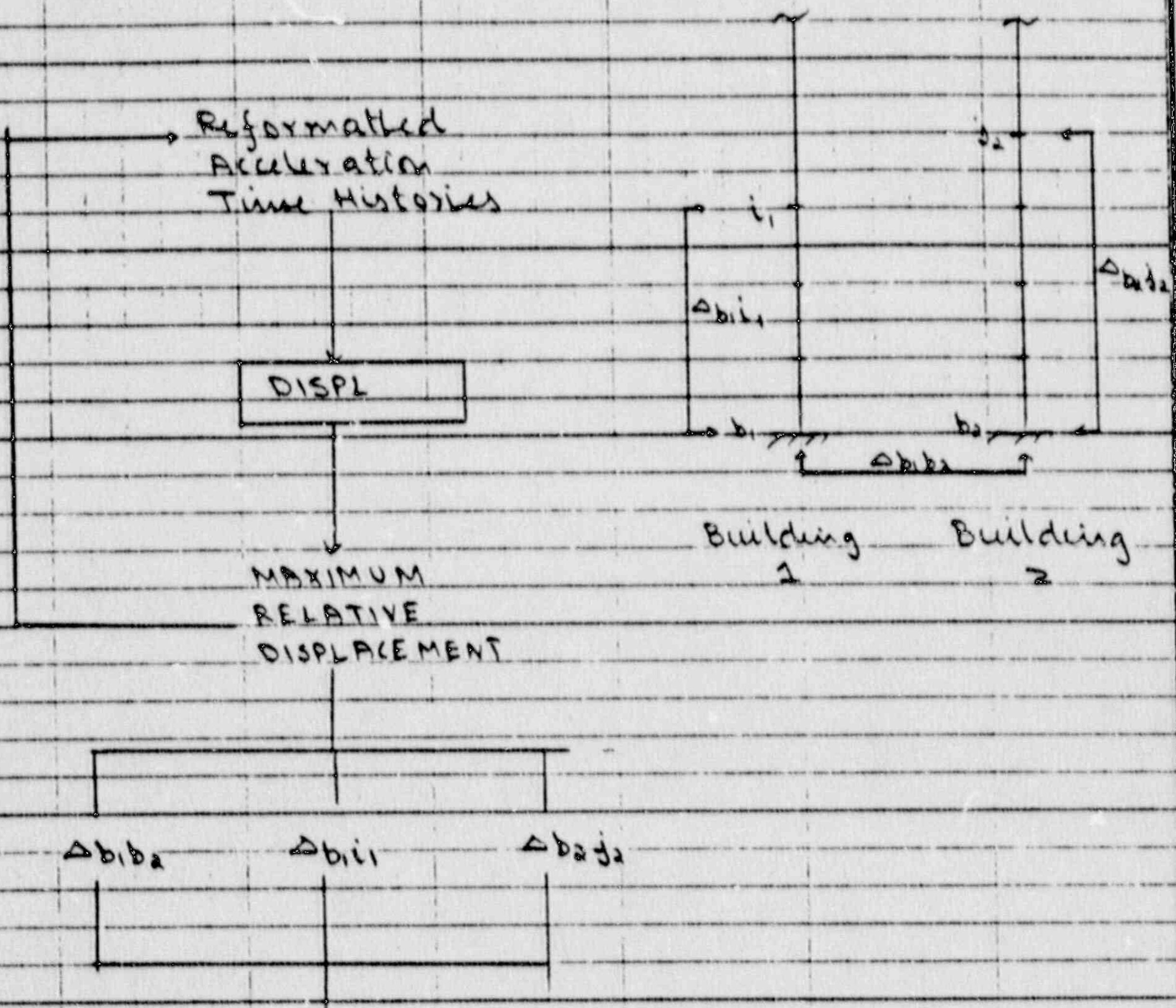
The above procedure assumes that:

(1) presence of building 1 does not affect response of building 2, and vice versa, and

(2) vertical propagating shear waves, and vertical propagating P-waves describe the earthquake motion.

The Methodology is shown in Fig 2.2.



$$S_{i_1j_2} = |\Delta_{b_1b_2}| + |\Delta_{b_1i_1}| + |\Delta_{b_2j_2}|$$

FIG. 2.2. METHODOLOGY FOR SEISMIC ANCHOR MOVEMENT BETWEEN TWO BUILDINGS

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3 FOUNDATION IMPEDANCES

The turbine building and turbine generator are supported by various types of piles [12]. Most of the piles are uplift piles. End-bearing piles are mostly under the generator pedestal only. Based on our experience of SSI analyses for this project, it has been observed that the piles do not contribute to the overall horizontal stiffness of the soil-foundation system significantly. Therefore, in the analysis of the Turbine Building the piles are not explicitly modeled. (continued on page 17a)

The Foundation mat of turbine building is assumed to be rigid. The mat is symmetric in both N-S and E-W directions. Dimensions of foundation mat are 239' in N-S direction and 124.5' in E-W direction [4]. Advantage is taken of symmetry and only 1/4 model of foundation is used to calculate foundation impedances

In the vertical direction, it is conservative for low frequencies to neglect the stiffness of piles. For high frequency response (predominantly rocking effect), ignoring piles is not significant because there are no end bearing piles at the outer edges of basemat. The piles for all the turbine building are floating piles. End bearing piles are only under the turbine generator foundation pedestal, which is approximately at the center of turbine building.

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Soil profile used in the GLAYER module of CLASSI is tabulated in Table 3.1. This profile is based on the high strain soil profile developed in [2]. CRL # for GLAYER is TURB-02-01

Characteristic length used in CLAF module of CLASSI is 119.5', and the subregions used to model 1/4 model of foundation are shown in Fig. 3.1. Dimension and centroid of subregions in terms of characteristic length are tabulated in Table 3.2. Subregions are more refined at the corners of the foundation.

Frequency dependent impedances are calculated explicitly for following 20 frequencies.

0.5, 1.5, 3.0, 4.5, 6.0, 7.5, 9.0, 10.5, 12.0, 13.50, 15.0, 16.5, 18.0, 20.0, 22.0, 24.0, 26.5, 29.0, 31.0 and 33.5 Hz

CRL # for CLAF is TURB-02-02

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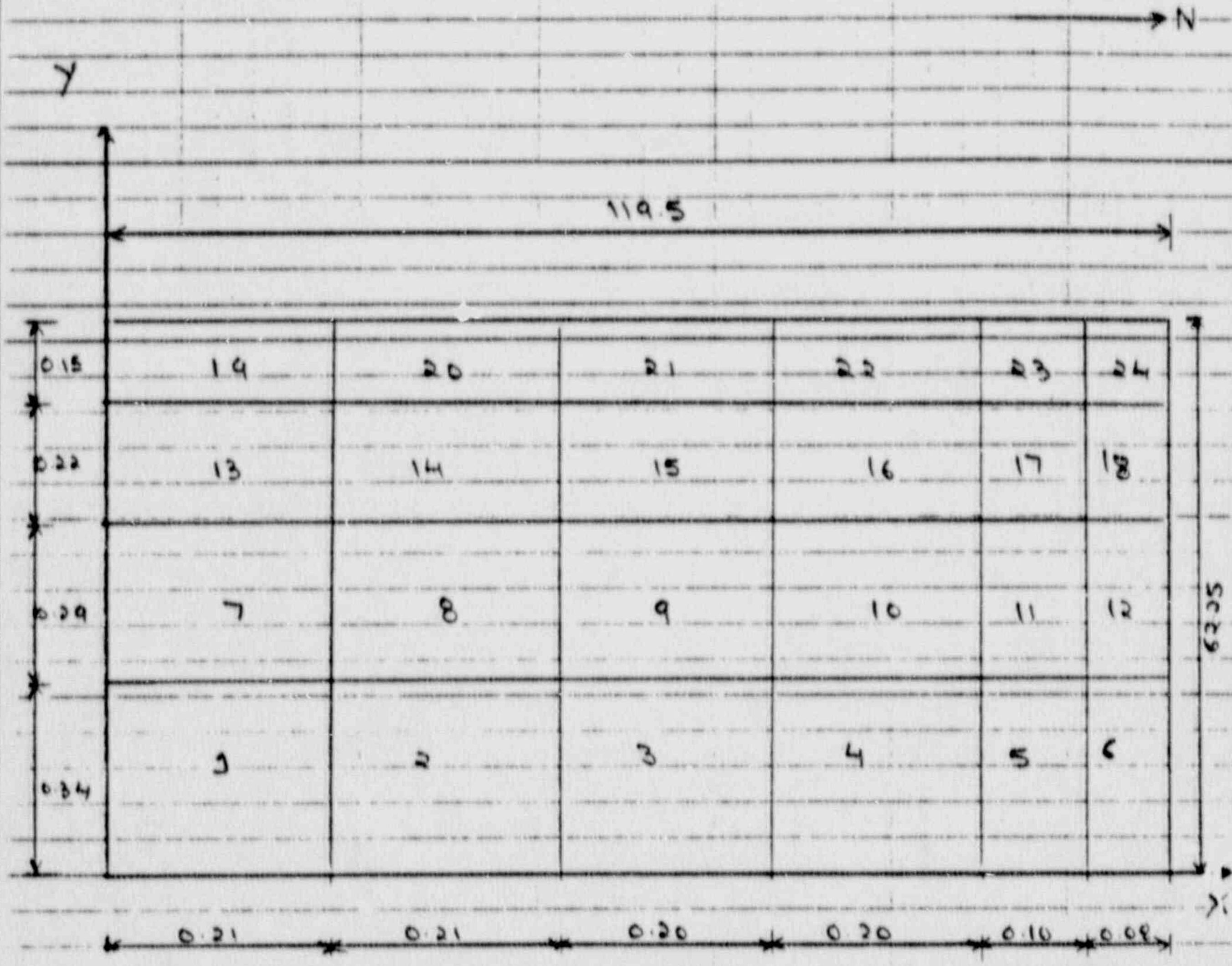

Characteristic Length = 119.5'

FIG. 3.1 SUBREGIONS FOR CLASS I / CLAF
(Y4 MAT ONLY)

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TABLE 3.1

SOIL PROFILE FOR TURBINE + OFFICE BUILDING

ν_{soil} = 0.475

ν_{rock} = 0.330

Layer No.	Thickness (ft)	Depth (ft)	Elevation (ft)	W (K/ft3)	V_s ft/s	G Ksf	V_p ft/s	ξ %
		0	998.08					
1	1.58	1.58	986.50	0.115	459	754	2103	.054
2	2.50	4.08	984.00	0.115	497	881	2278	.057
3	2.50	6.58	981.50	0.124	509	997	2332	.060
4	2.50	9.08	979.00	0.124	535	1103	2452	.062
5	5.00	14.08	974.00	0.124	507	991	2323	.072
6	5.00	19.08	969.00	0.124	539	1120	2470	.074
7	5.00	24.08	964.00	0.124	567	1240	2598	.075
8	5.00	29.08	959.00	0.124	569	1246	2607	.078
9	5.00	34.08	954.00	0.124	577	1281	2644	.080
10	5.00	39.08	949.00	0.124	551	1169	2525	.086
11	5.00	44.08	944.00	0.124	565	1231	2589	.086
12	5.00	49.08	939.00	0.130	565	1290	2589	.088
13	5.00	54.08	934.00	0.130	579	1352	2653	.098
Half-Space				0.155	3140	47461	6234	0.075

ν = Poisson's Ratio   ξ = Damping Ratio

w = Weight Density   G = Shear Modulus

V_s = S-Wave Velocity V_p = P-Wave Velocity

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TABLE 3.2

SUBREGIONS GEOMETRY IN CHARACTERISTIC LENGTH

Subregion #	Centroid X	Centroid Y	Dimension X	Dimension Y
1	0.105	0.0886	0.21	0.1771
2	0.315	0.0886	0.21	0.1771
3	0.520	0.0886	0.20	0.1771
4	0.720	0.0886	0.20	0.1771
5	0.870	0.0886	0.10	0.1771
6	0.960	0.0886	0.08	0.1771
7	0.105	0.2526	0.21	0.1511
8	0.315	0.2526	0.21	0.1511
9	0.520	0.2526	0.20	0.1511
10	0.720	0.2526	0.20	0.1511
11	0.870	0.2526	0.10	0.1511
12	0.960	0.2526	0.08	0.1511
13	0.105	0.3855	0.21	0.1146
14	0.315	0.3855	0.21	0.1146
15	0.520	0.3855	0.20	0.1146
16	0.720	0.3855	0.20	0.1146
17	0.870	0.3855	0.10	0.1146
18	0.960	0.3855	0.08	0.1146
19	0.105	0.4819	0.21	0.0781
20	0.315	0.4819	0.21	0.0781
21	0.520	0.4819	0.20	0.0781
22	0.720	0.4819	0.20	0.0781
23	0.870	0.4819	0.10	0.0781
24	0.960	0.4819	0.08	0.0781

4 STRUCTURAL MODEL

The structural model for turbine building + turbine generator + turbine generator foundation is developed in Impell calc. TURB-01 [1]. Refer to Section 2.2 of Ref 1 for model sketch and other details or attachment A.

Material properties used in model are

Concrete: E = 519,000 ksf

ν = 0.17

f'_c = 4000 psi Class B Conc.

Steel: E = 4,176,000 ksf

ν = 0.25

4% structural damping is used (conserv.) This is the recommended damping for welded steel structures for SSE event [16].

Mode shapes and frequencies are calculated, and mode shapes plotted in Impell calc. TURB-01 [1]. However they are recalculated in computer run # TURB-02-03. Program RDDATA [13] is

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then used to reformat mode shapes & frequencies so that they can be used as input for SSIN module.

CRL # for RDDATA is TURB-02-04

5 INPUT TIME HISTORIES

Input time histories for SSI analyses are

T.H. 132 - N-S Direction

T.H. 134 - E-W "

TH 151 - VER. " .

See Impell calc. THG-01 [2] for more details on these time histories.

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6. BROADENED FLOOR SPECTRA

Broadened floor spectra for SSE event are calculated for Mezzanine floor at elevation 1011' and operating floor at elevation 1036'. Response spectra are calculated at base of building. Acceleration time histories are also calculated at center of mass for elevation 1051', 1073.5' and 1092.9' of turbine + office building, and for elevation 1036' of turbine generator Foundation. These time histories are required for Seismic Anchor Movements. Computer run nos. used to perform above tasks are as follows.

Run #	Task
TURB-02-05	Accn. T.H. for elevation 1011'
TURB-02-06	Accn. T.H. for elevation 1036
TURB-02-07	Accn. T.H. for center of Mass at other elevations
TURB-02-08 to 09	Response spectra at Base
TURB-02-10 to 16	Design floor spectra at 1011'
TURB-02-17 to 23	Design floor spectra at 1036

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IMPELL CORPORATION

JOB NO 1390-027-1355

CALC NO TURB-02

o Structural node nos. at various floor elevations are as follows [1].

Building	Floor Elevation (ft)	Node Nos.
Turbine + Office	990.0'	32, 33, 34, 35, 36, 37, 38
Turbine + Office	1011.0'	42, 43, 44, 45, 46, 47, 48
Turbine + Office	1036.0'	52, 53, 54, 55, 56, 57, 58
Turbine + Office	1051.0'	62, 63, 64, 65, 66, 67, 68
Turbine + Office	1073.5'	72, 73, 75, 76, 77, 78
Turbine + Office	1092.9'	82, 84, 85, 86, 87, 88
T. Gen. Found	990.0'	92
T. Gen. Found	1011.0'	112
T. Gen. Found	1036.0'	132

Underline node is the center of mass node for the floor elevation.

REV	BY	DATE	CHECKED	DATE
0	RA	6/7/88	AD	6/29/88

IMPELL CORPORATION

JOB NO 1390-027-1355
CALC NO TURB-02

Translational degrees of freedom associated with structural nodes, where acceleration time histories are calculated , as follows:

Refer to CPL # TURB-02-03

Node No.	X	Y	Z
42	31	32	33
45	37	38	39
46	43	44	45
47	49	50	51
48	55	56	57
52	61	62	63
55	67	68	69
56	73	74	75
57	79	80	81
58	85	86	87
62	91	92	93
72	121	122	123
82	151	152	153
132	193	194	195

REV	BY	DATE	CHECKED	DATE
0	RA	6/7/88	GAD	6/9/88

IMPELL CORPORATION

JOB NO 1390-027-1355

CALC NO TURB-02

Response spectra at base for 0.5%, 1% and 5% damping are shown in Fig. 6.1, 6.2 and 6.3 for N-S, E-W and Ver. directions. These are compared with Figs. F-19 (N-S and E-W) and Fig F24 (Ver) of NSAR appendix F [14].

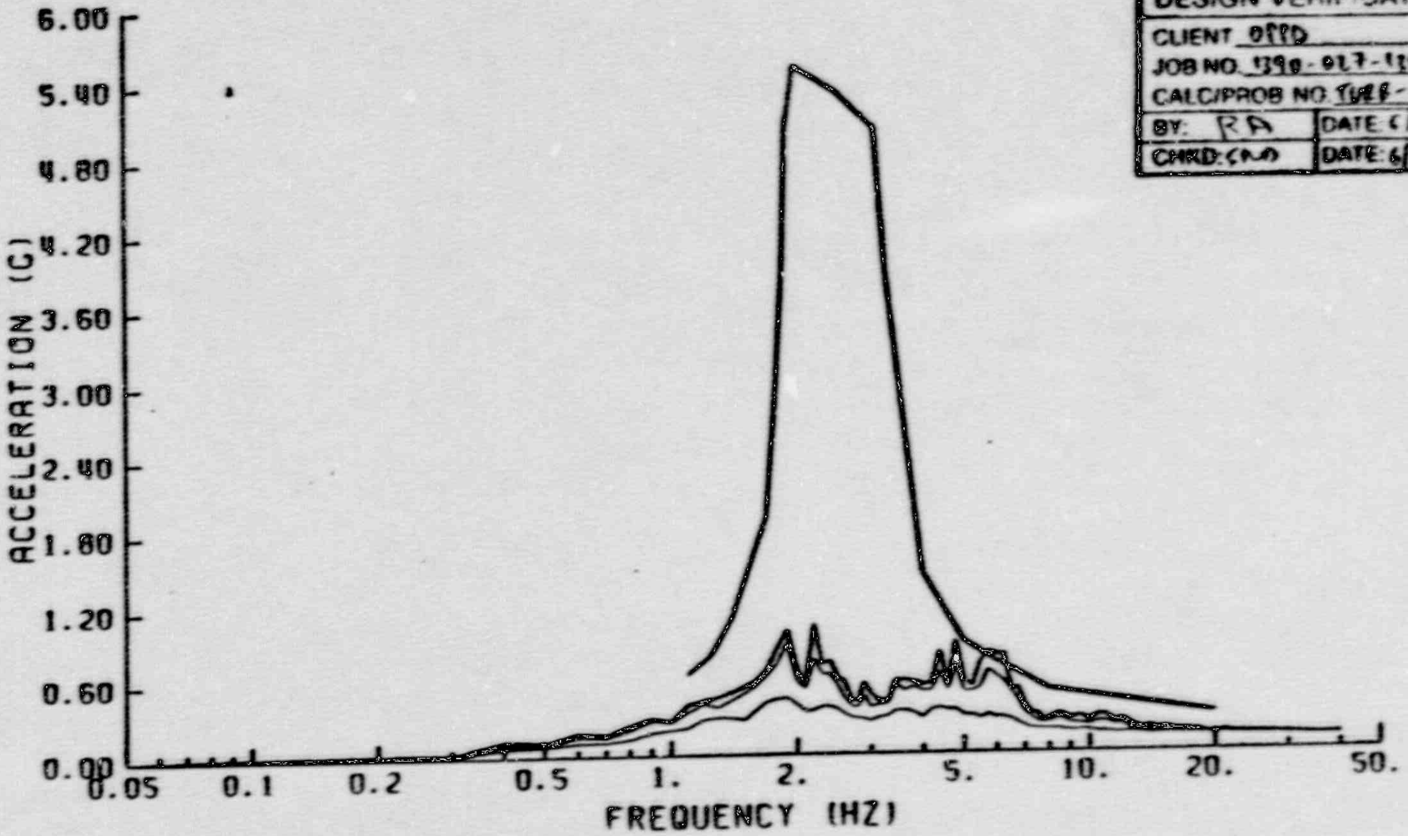
Broadened spectra at elevation 1011' and 1036' at 2%, 5%, 7%, 10%, 15% and PVRC damping are shown in Figs. 6.4 through 6.39.

For elevation 1011', response spectra are calculated at center of mass node (32) and at four corners of the floor (nodes: 35, 36, 37 and 38) in X (N-S), Y (E-W) and Z (VER.) directions. Similarly, for elevation 1036', response spectra are calculated at center of mass (node 52) and at four corners of the floor (nodes: 65, 66, 67 and 68) in all the three directions. The enveloped spectra, which envelops spectra at above five locations on a floor, is broadened by 15% using program SPECT1A [9].

0	RA	6/7/84	SND	6/9/84	IMPELL CORPORATION
REV	BY	DATE	CHECKED	DATE	

JOB NO 1390-027-1355
CALC NO TURB-02

FIG. 6.1

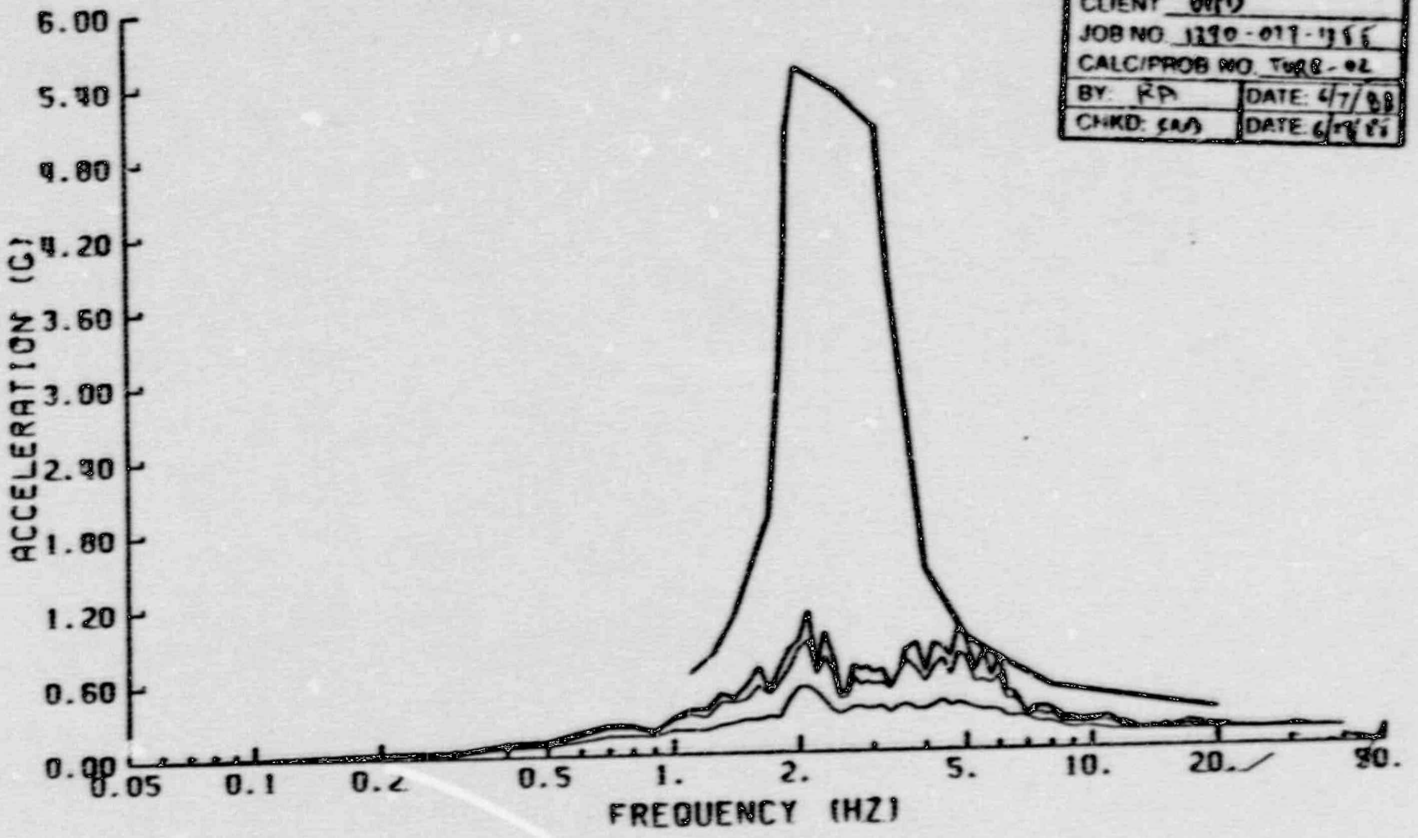


DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1358	
CALC/PROB NO. TURB-02	
BY: RA	DATE 6/7/88
CHKD: CAD	DATE 6/29/88

OPPD TURBINE SSI ANALYSIS
LOCATION = BASE DIR.= N-S
DS = DESIGN (1 PERCENT) DAMPING = 0.5, 1, 5 PERCENT

FIG. 6.2

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-019-956	
CALC/PROB NO. TURB-02	
BY: KP	DATE: 6/7/88
CHKD: SAS	DATE: 6/19/88



OPPD TURBINE SSI ANALYSIS
LOCATION = BASE DIR. = E-W
DS = DESIGN (1 PERCENT) DAMPING = 0.5, 1, 5 PERCENT

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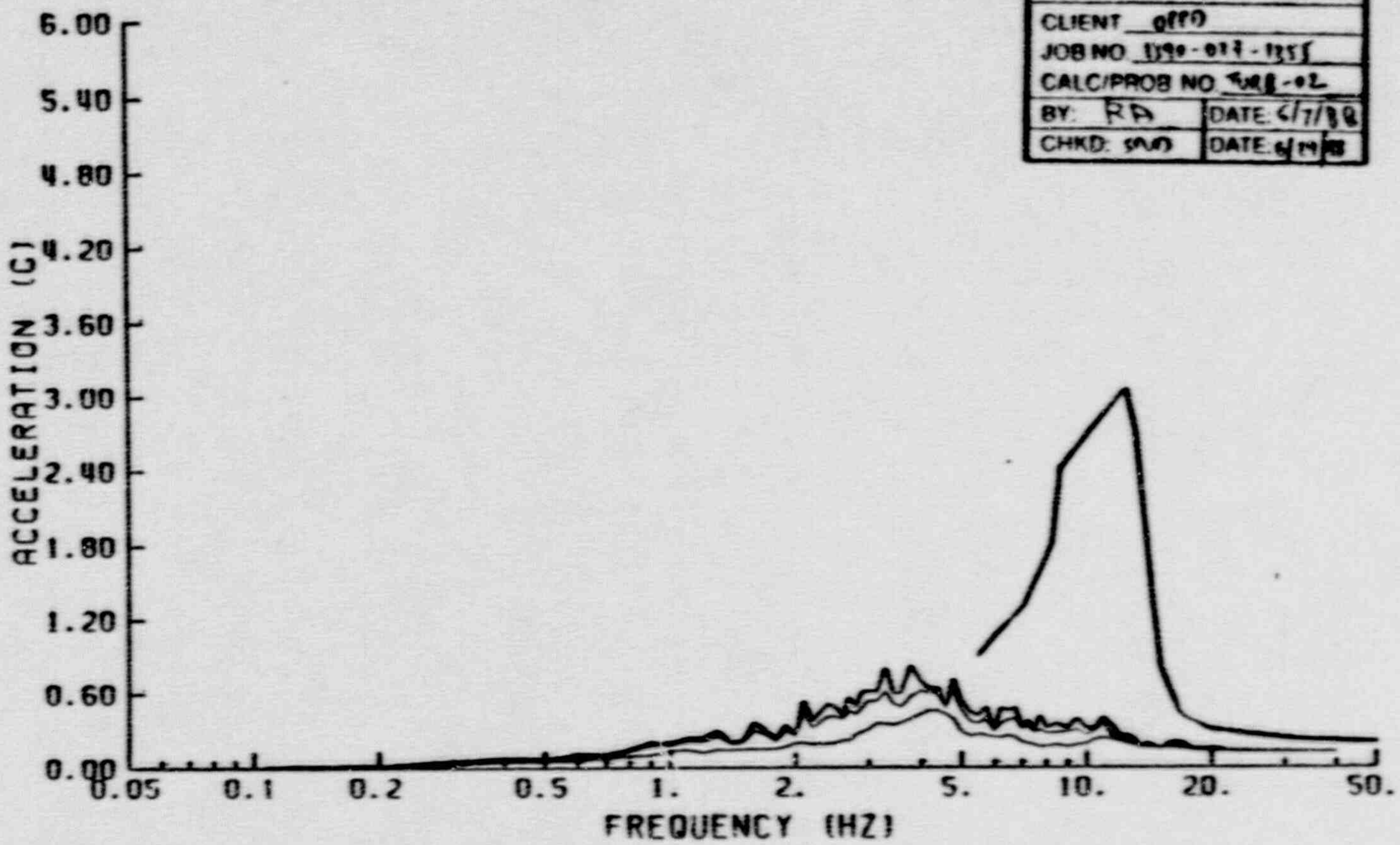
FIG. 6.3

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-017-1355	
CALC/PROB NO. TURB-02	
BY: RA	DATE: 6/7/88
CHKD: SAD	DATE: 6/14/88



OPPD TURBINE SSI ANALYSIS
LOCATION = BASE DIR.= V
DS = DESIGN (.5 PERCENT) DAMPING = 0.5, 1, 5 PERCENT

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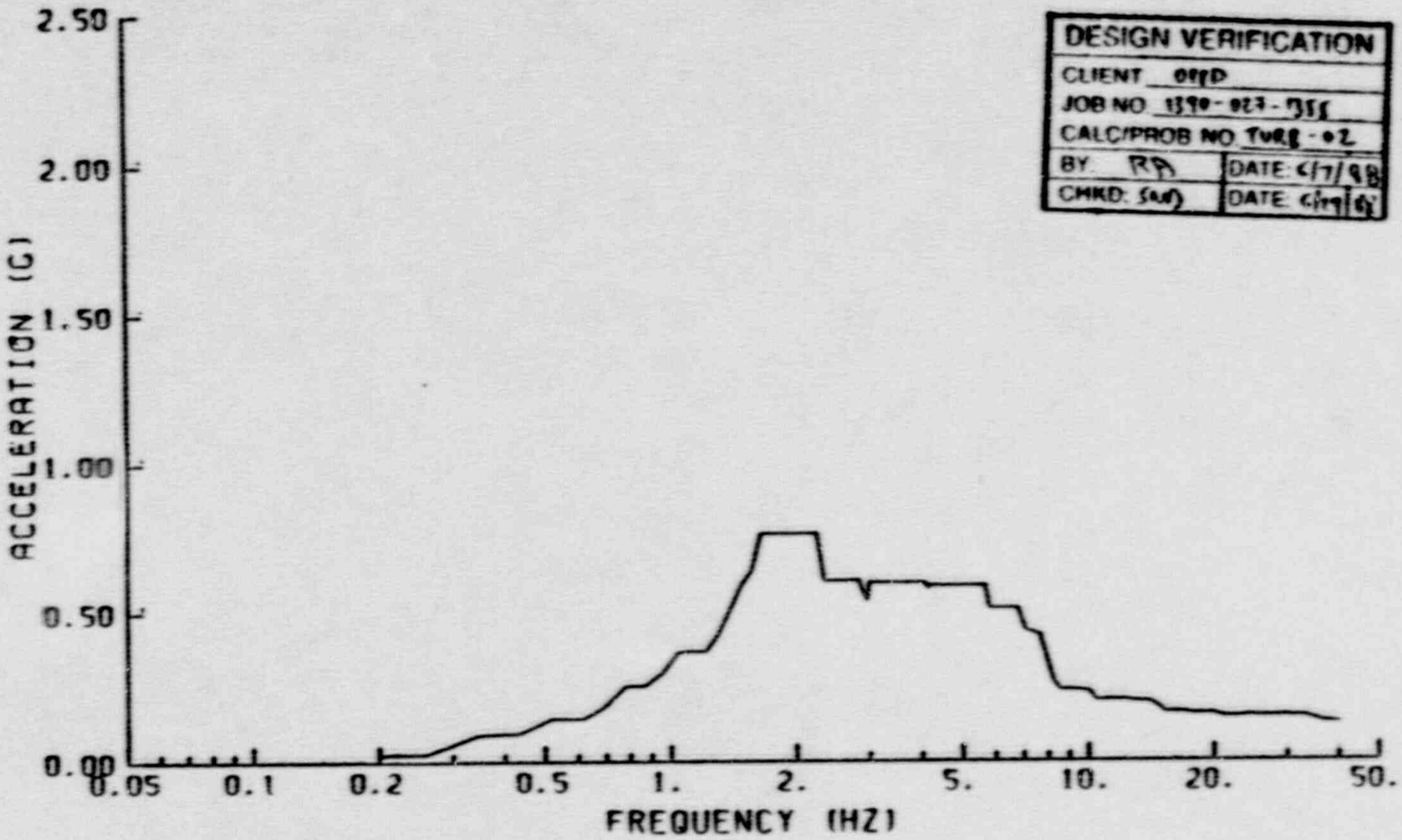
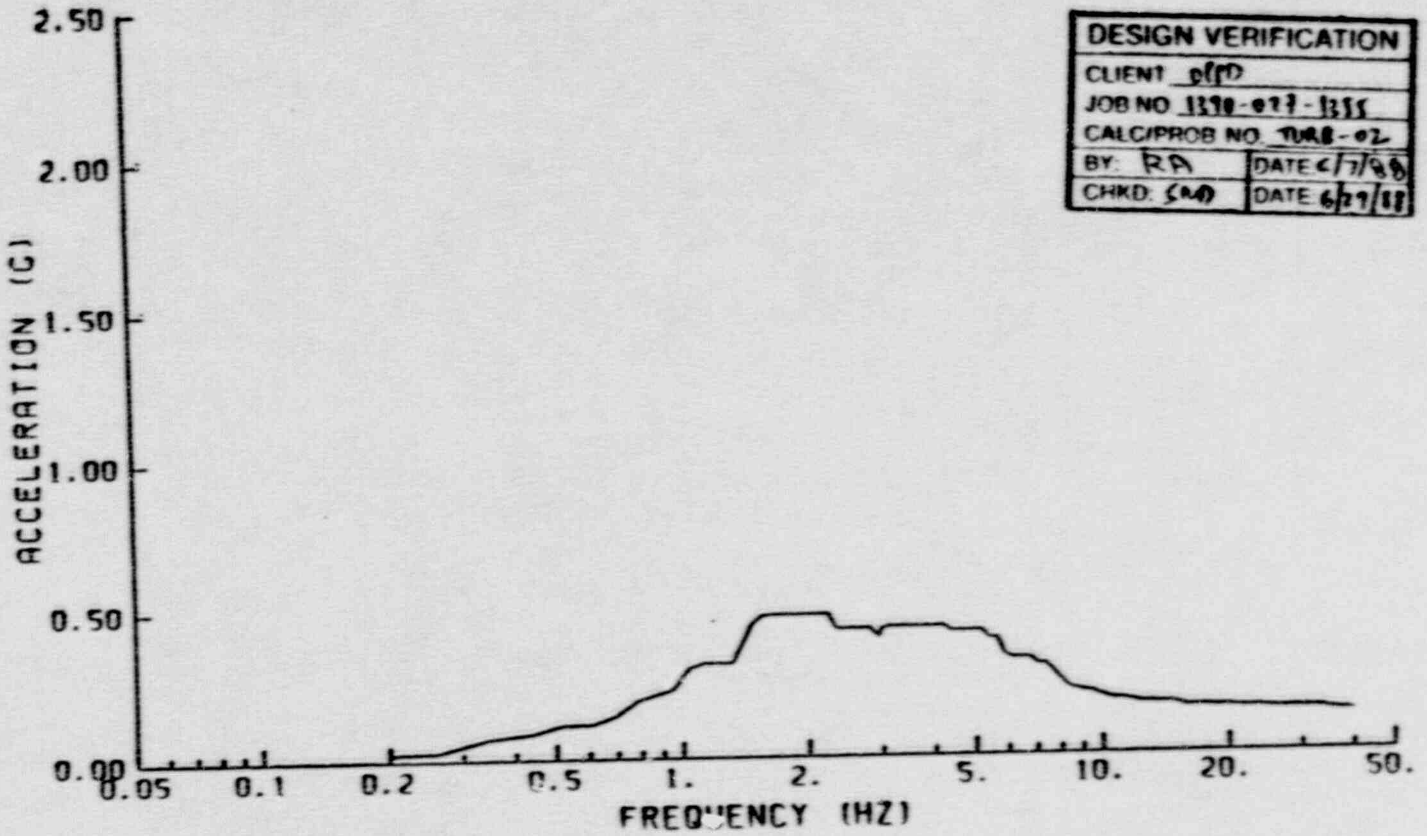
FIG 6.4



DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO 1390-027-355	
CALC/PROB NO TURB-02	
BY RA	DATE 6/7/98
CHKD SWJ	DATE 6/19/98

OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1011 FT-0 IN DIR.= N-S
DAMPING = 2 PERCENT

FIG. C.5



DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO 1390-077-1355	
CALC/PROB NO. TURB-02	
BY: RA	DATE 6/7/88
CHKD: SAD	DATE 6/29/88

OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1011 FT-0 IN DIR.= N-S
DAMPING = 5 PERCENT

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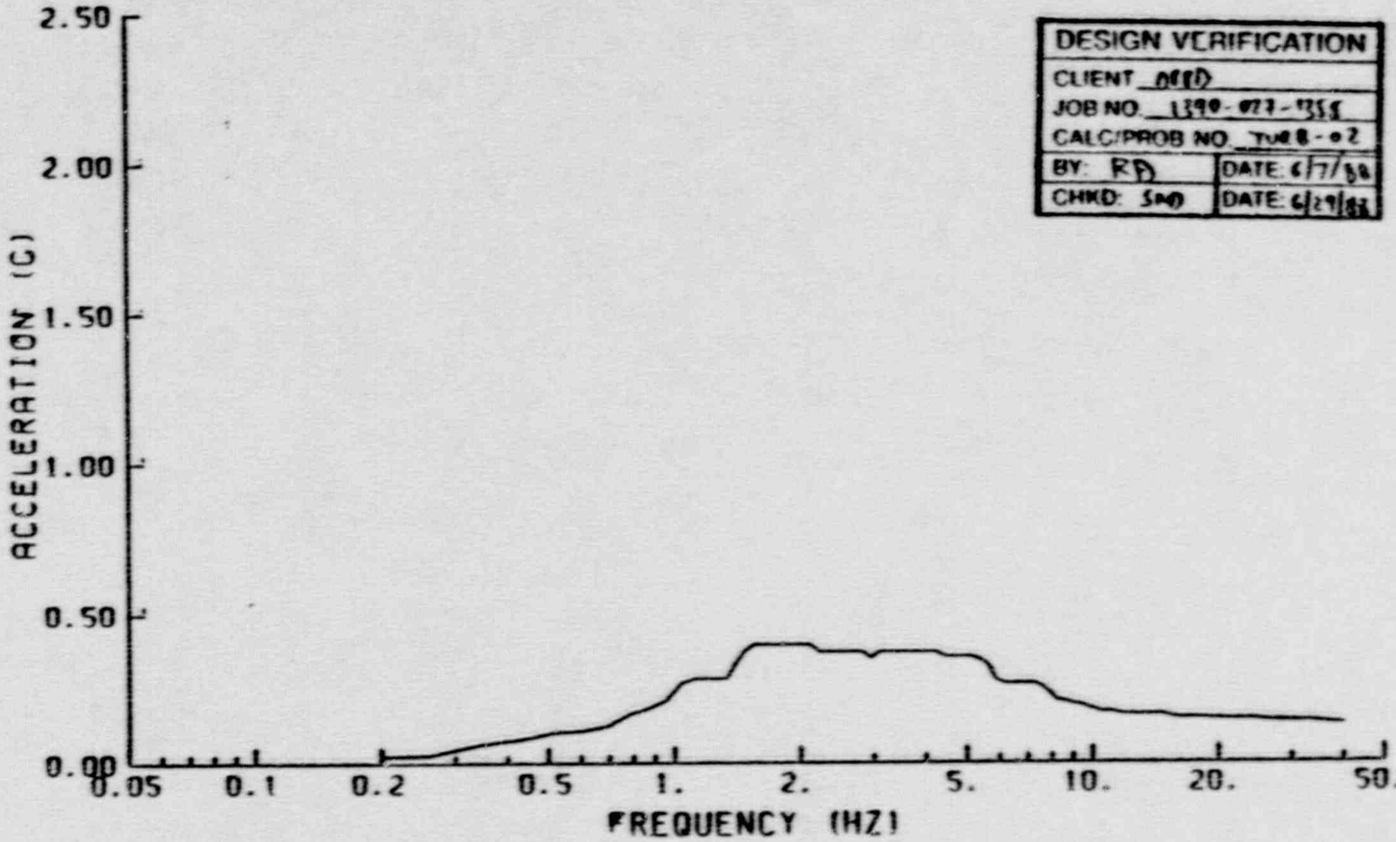
FIG. C.6



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV. = 1011 FT-0 IN DIR. = N-S
DAMPING = 7 PERCENT

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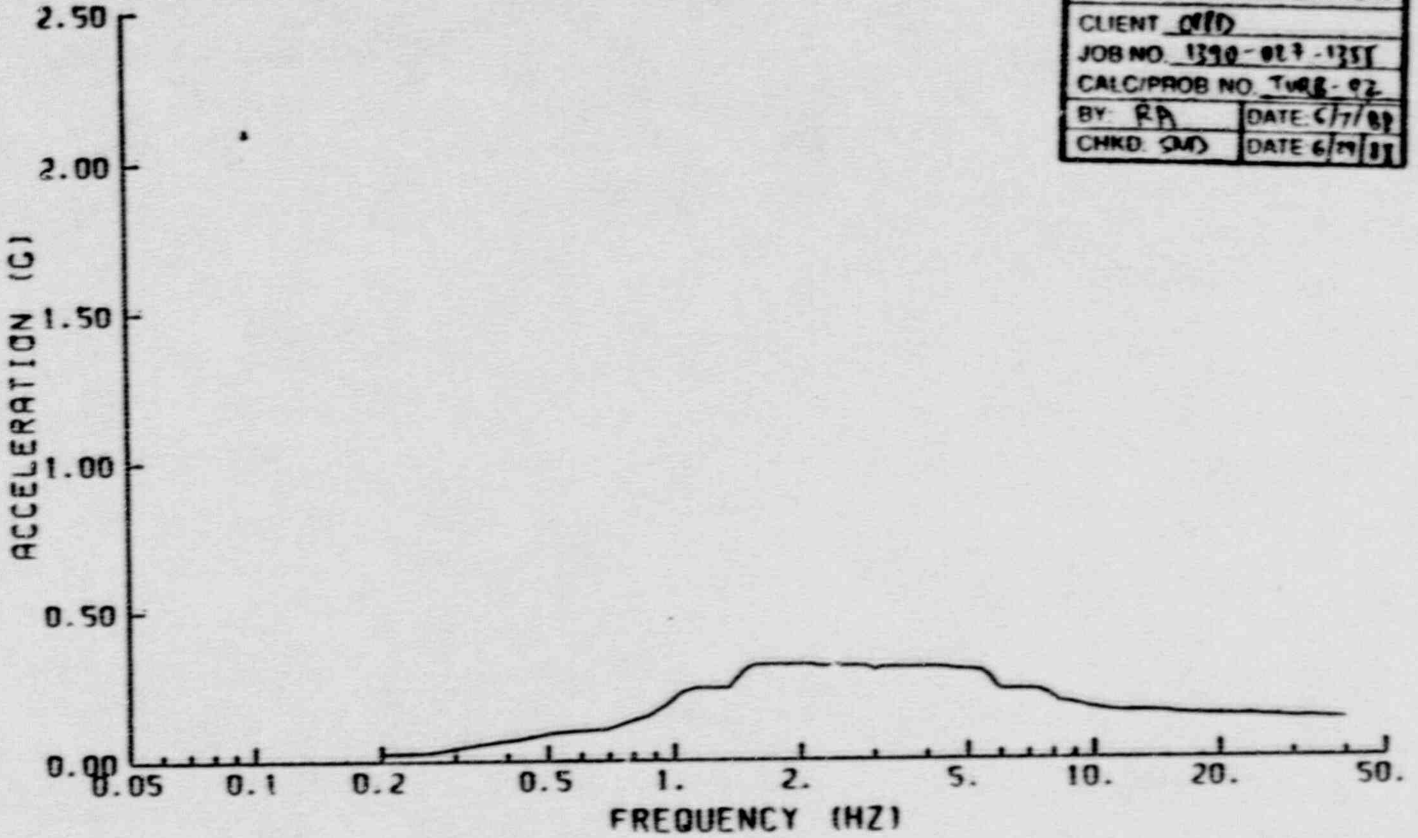
FIG. 6.7

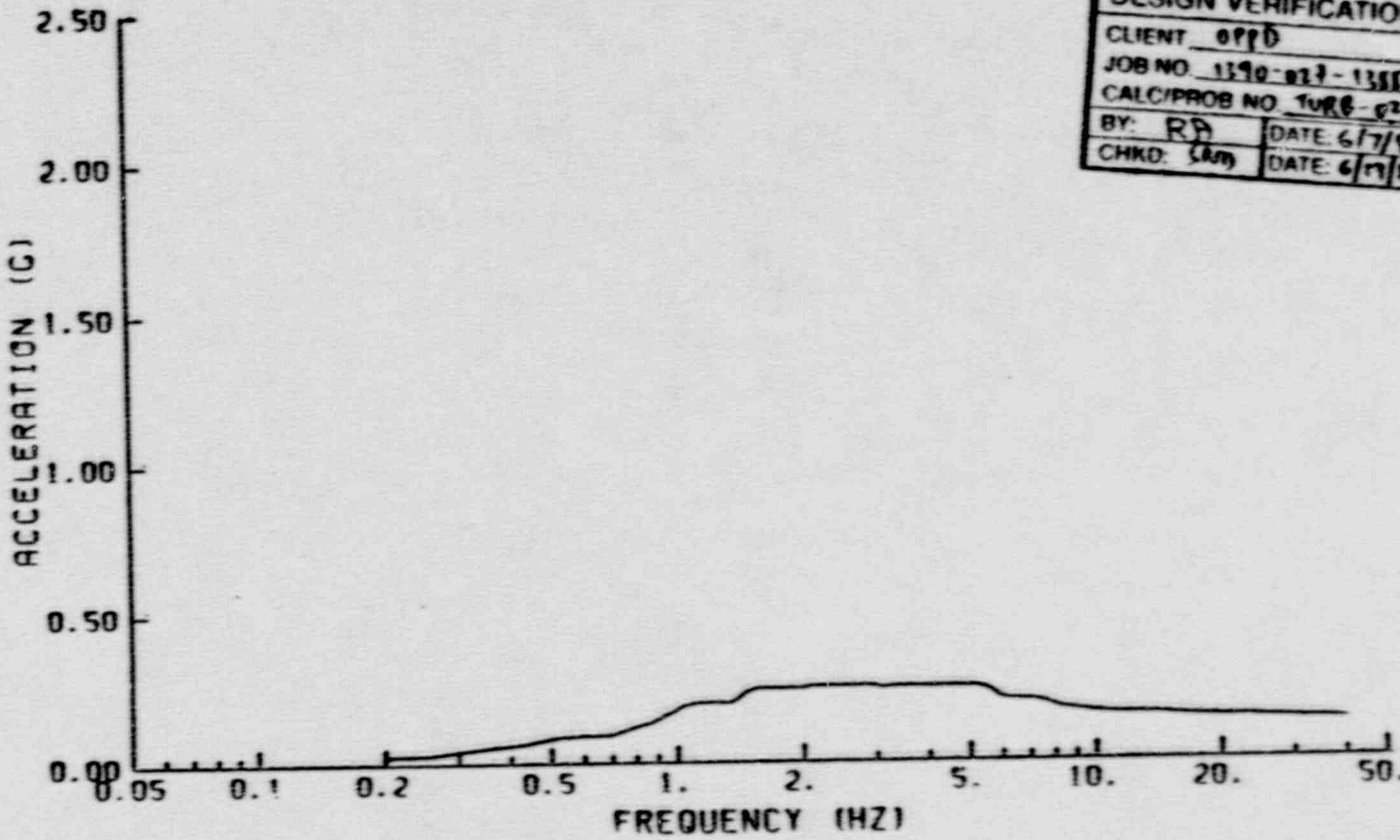
DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1355	
CALC/PROB NO. TURB-02	
BY: RA	DATE: 6/7/89
CHKD: SMD	DATE: 6/29/89



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV. = 1011 FT-0 IN DIR. = N-S
DAMPING =10 PERCENT

FIG. 6.8

DESIGN VERIFICATION
CLIENT OPPD
JOB NO. 1390-027-1355
CALC/PROB NO. TURB-02
BY: RA DATE: 6/7/88
CHKD: SAM DATE: 6/17/88



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1011 FT-0 IN DIR.= N-S
DAMPING =15 PERCENT

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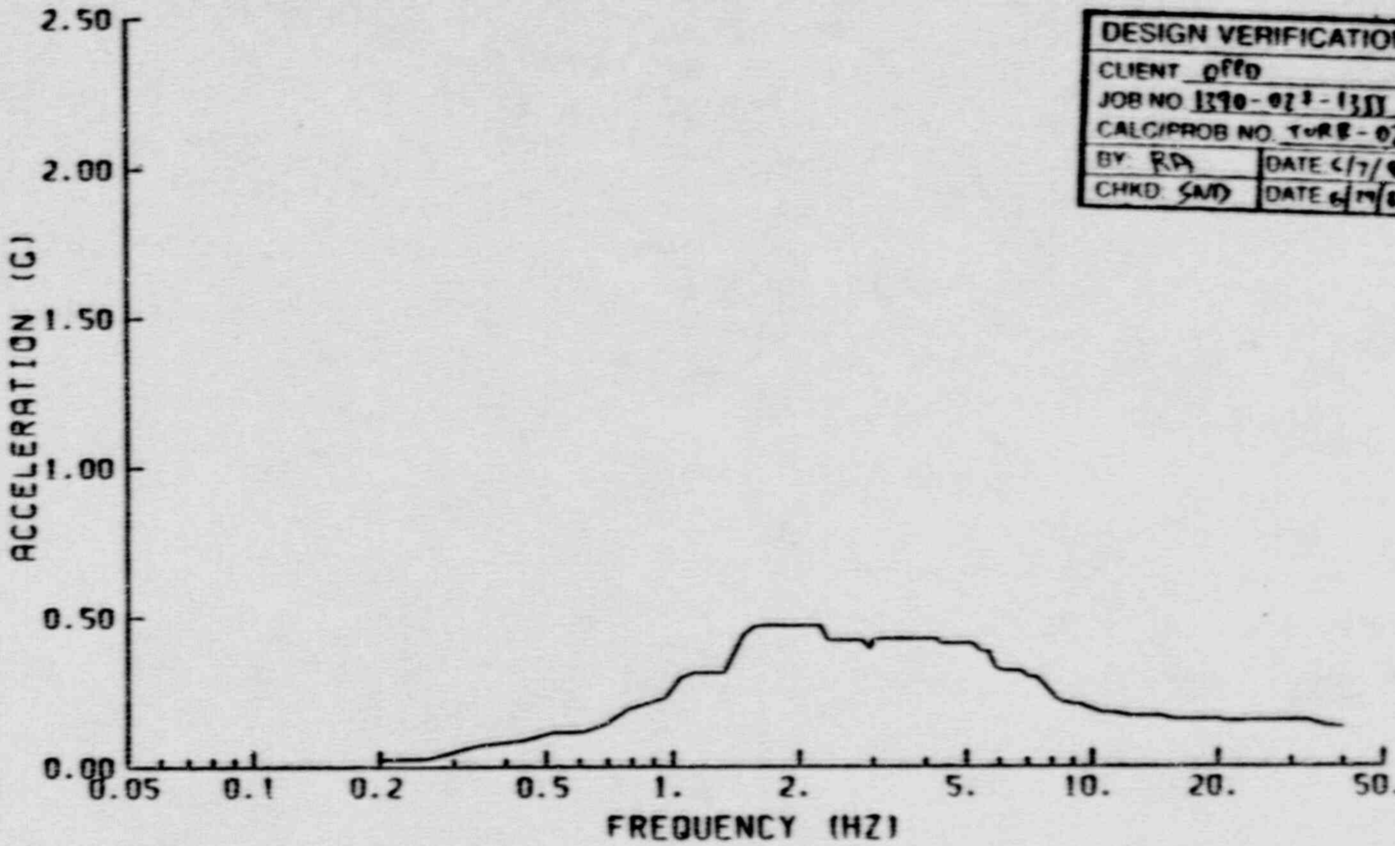
FIG. C.9



DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO 1390-028-1355	
CALC/PROB NO. TURB-02	
BY: RA	DATE 6/7/88
CHKD: SMD	DATE 6/14/88

OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV. = 1011 FT-0 IN DIR. = N-S
DAMPING = PVRC

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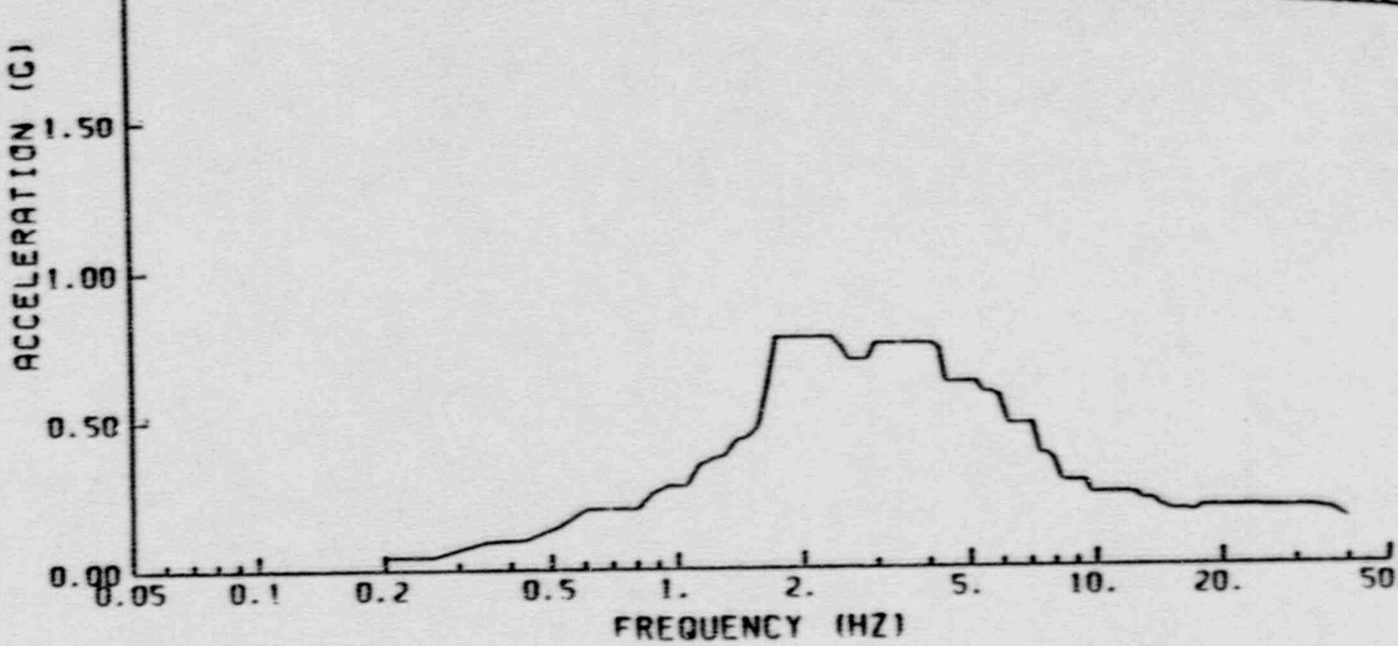
FIG. 6.10

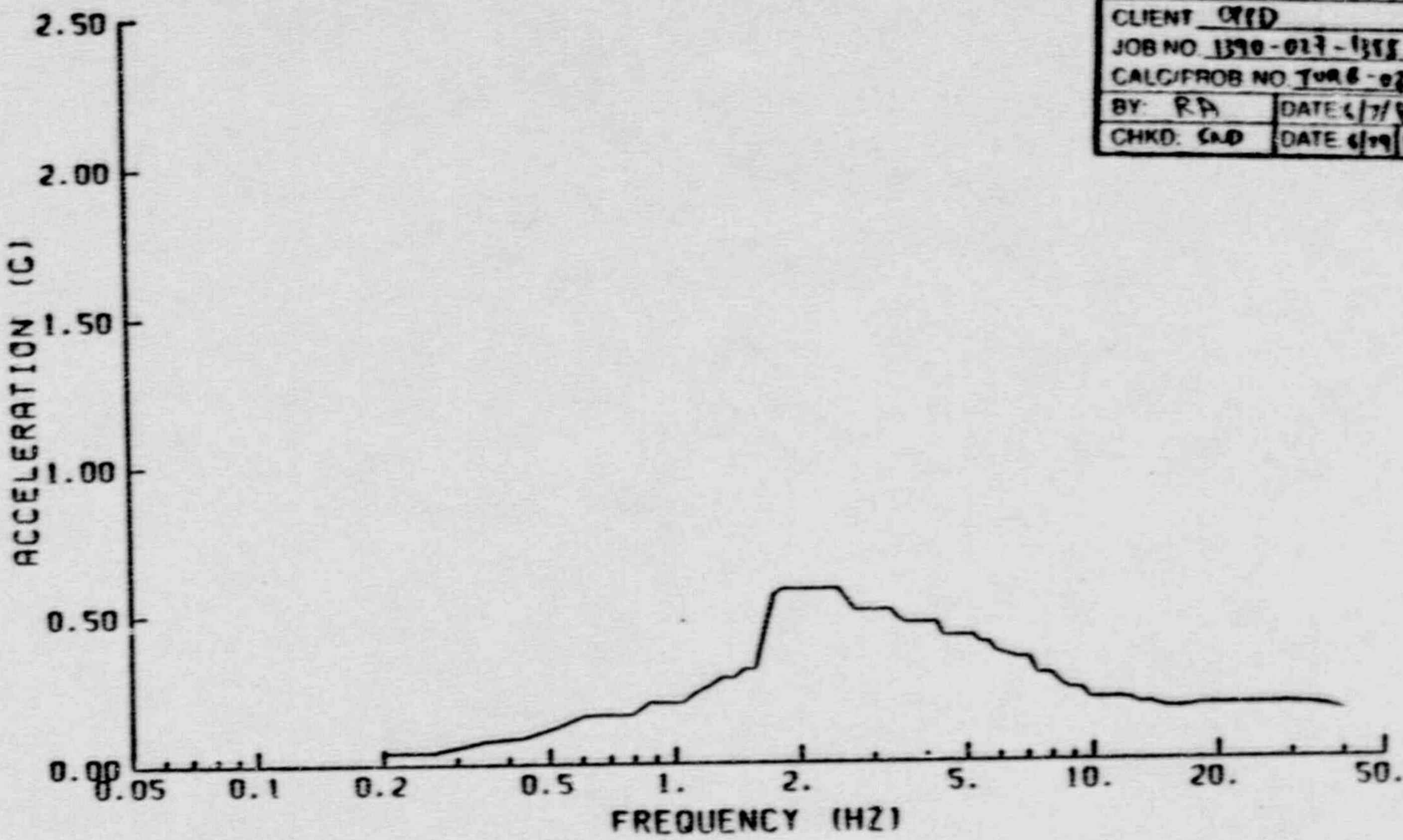
DESIGN VERIFICATION
CLIENT OPPD
JOB NO. 1390-073-1355
CALC/PROB NO. TURB-02
BY: RA | DATE: 6/7/88
CHKD: GMD | DATE: 6/29/88



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1011 FT-0 IN DIR.= E-W
DAMPING = 2 PERCENT

FIG. C.11

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1355	
CALC/PROB NO. TURB-02	
BY: RA	DATE 6/7/88
CHKD: GND	DATE 6/29/88



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1011 FT-0 IN DIR.= E-W
DAMPING = 5 PERCENT

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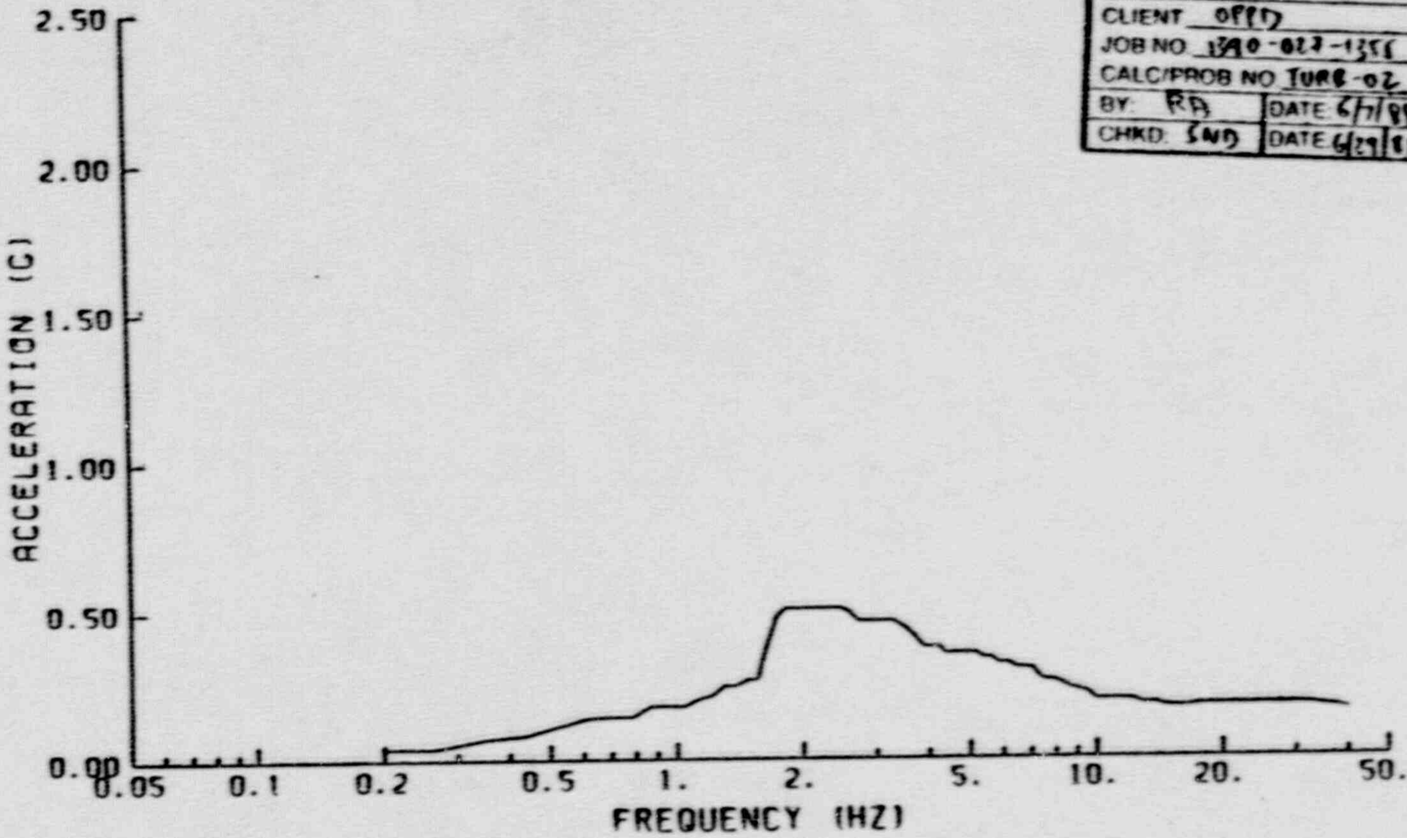
FIG. (12

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1355	
CALC/PROB NO. TURB-02	
BY: RA	DATE 6/7/88
CHKD: SND	DATE 6/29/88



OPPD/FT. CALHOUN UNIT 1, DES'GN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1011 FT-0 IN DIR.= E-W
DAMPING = 7 PERCENT

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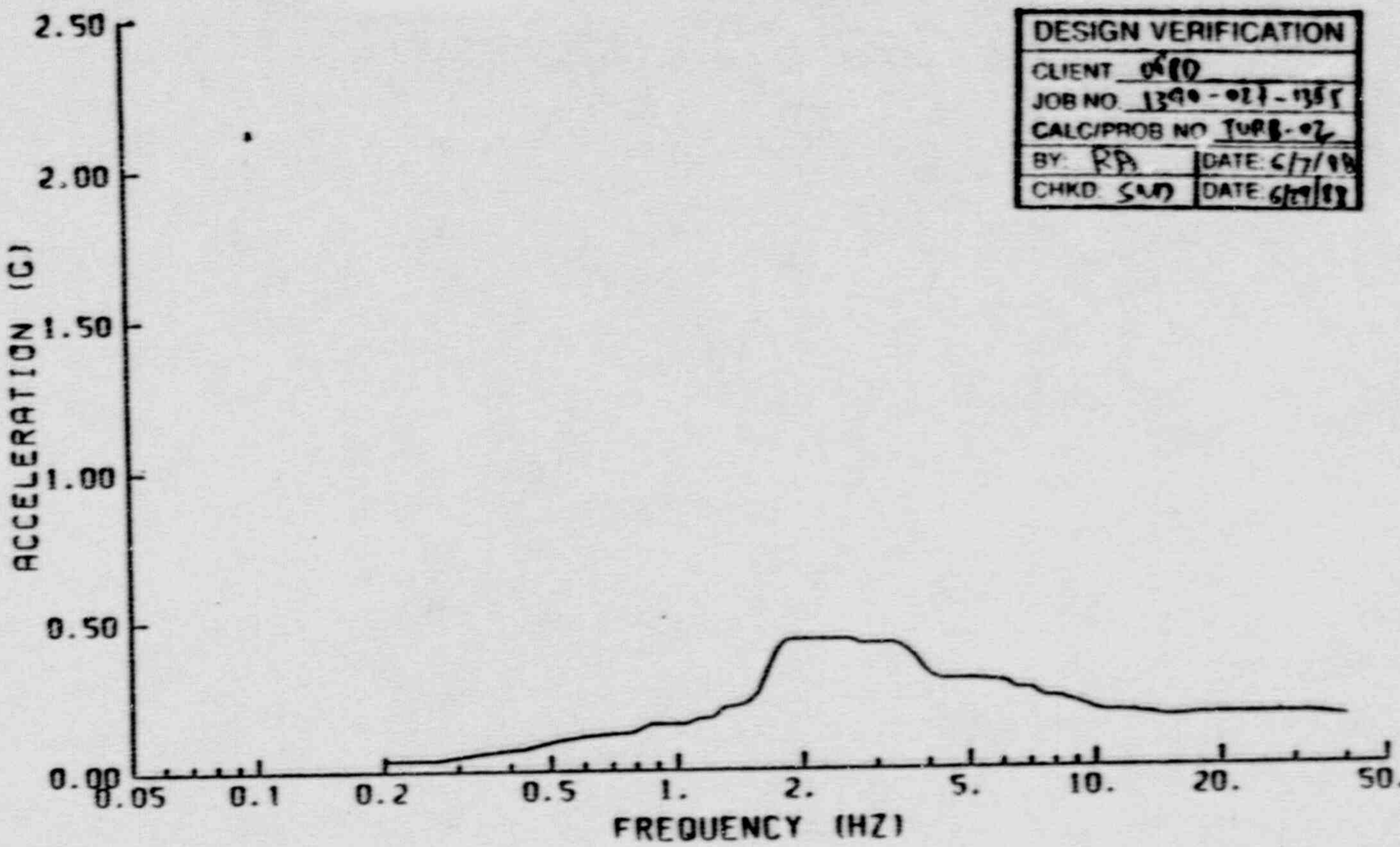
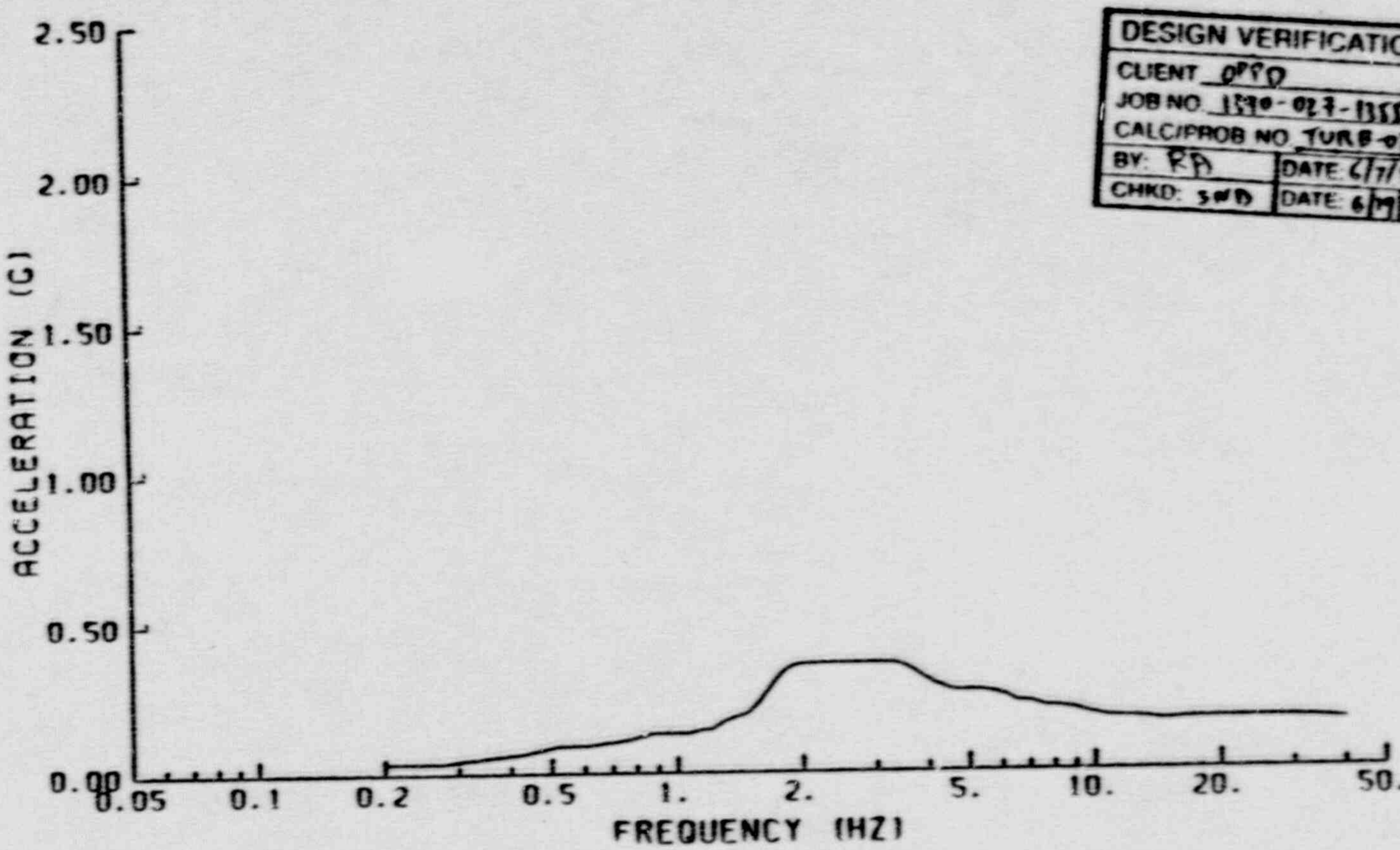
FIG. 6.13



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1011 FT-0 IN DIR.= E-W
DAMPING =10 PERCENT

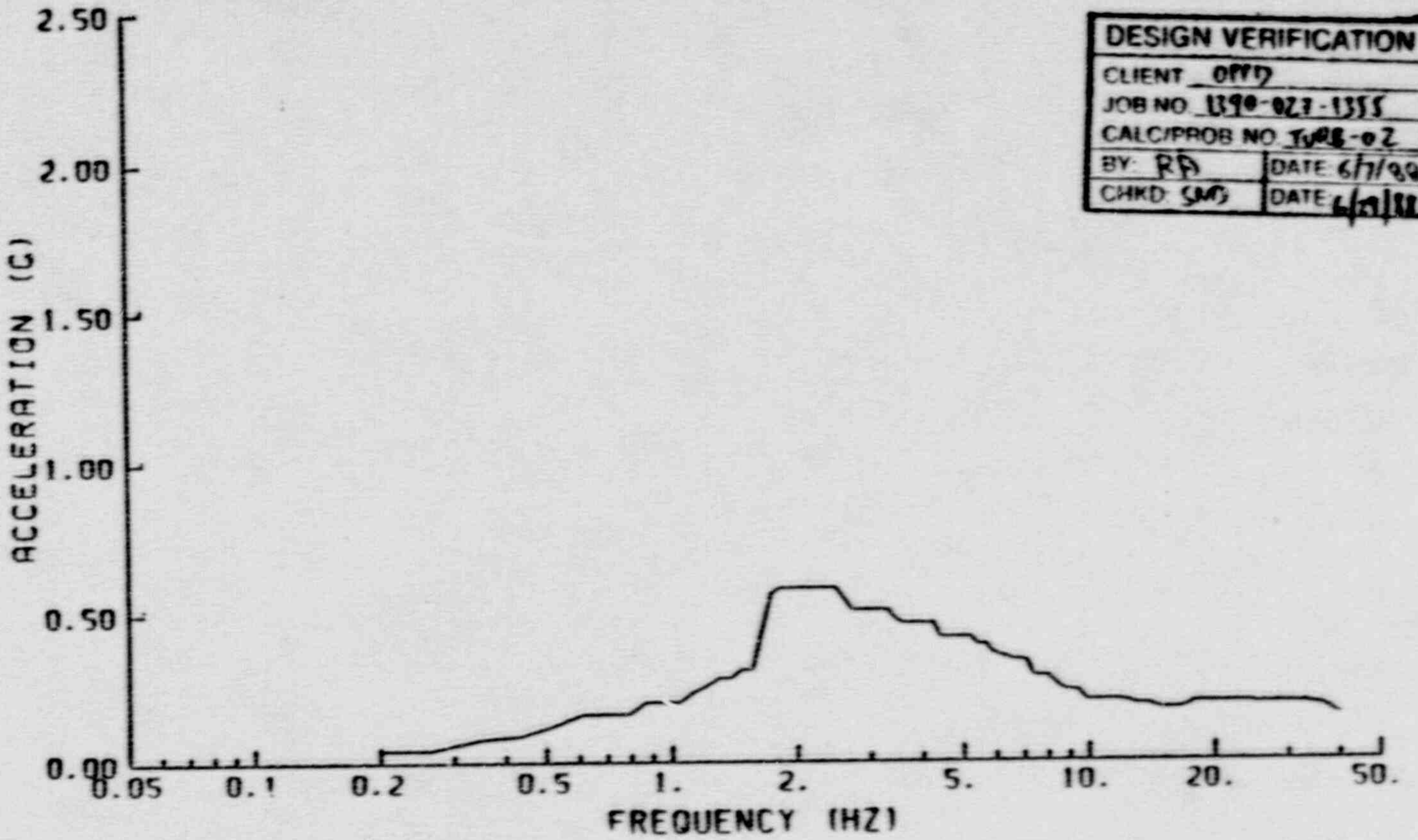
FIG. 6.14

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1590-027-1355	
CALC/PROB NO. TURB-02	
BY: RA	DATE: 6/7/88
CHKD: SWD	DATE: 6/19/88



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1011 FT-0 IN DIR.= E-W
DAMPING =15 PERCENT

FIG. C.15



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV. = 1011 FT-0 IN DIR. = E-W
DAMPING = PVRC

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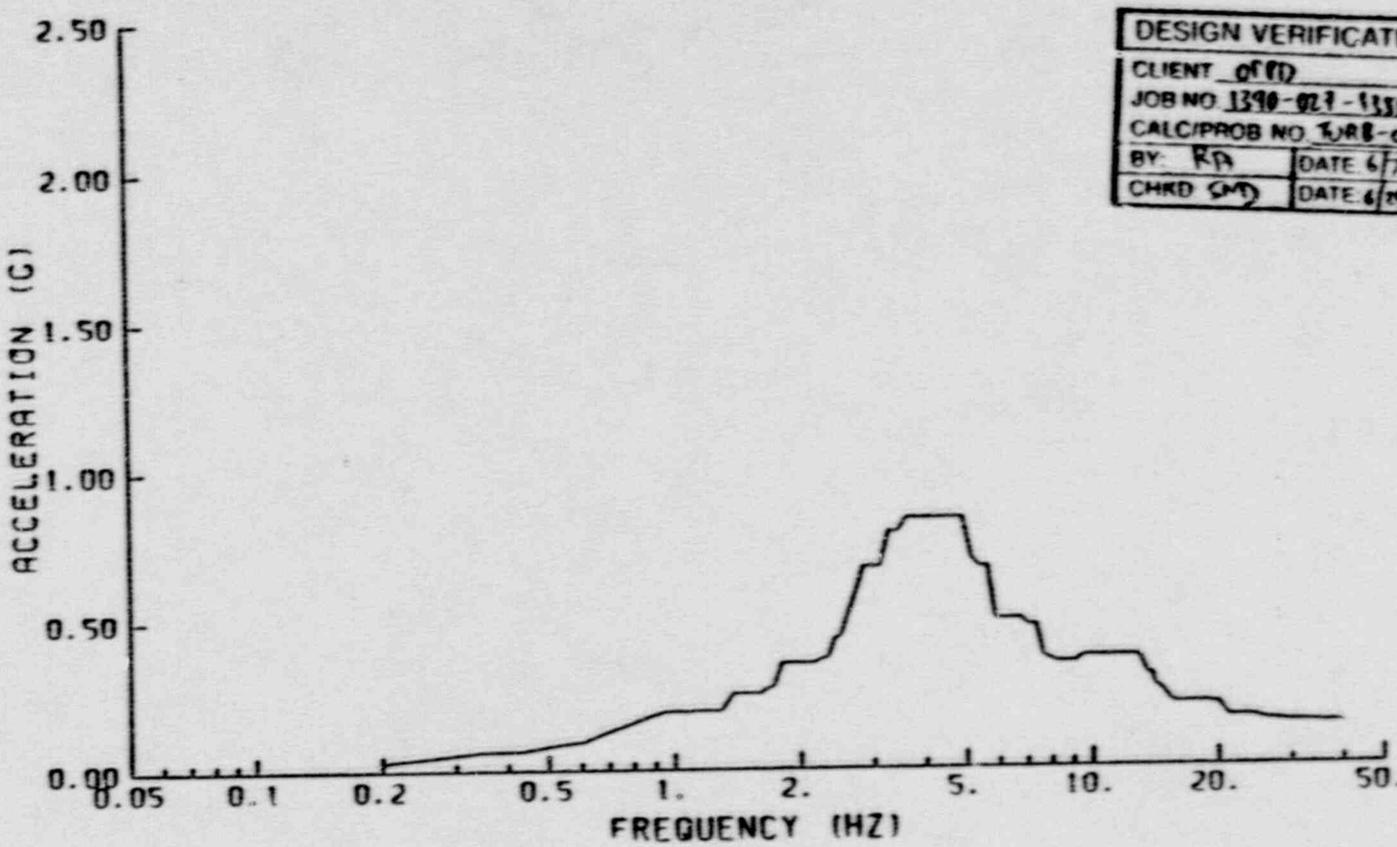
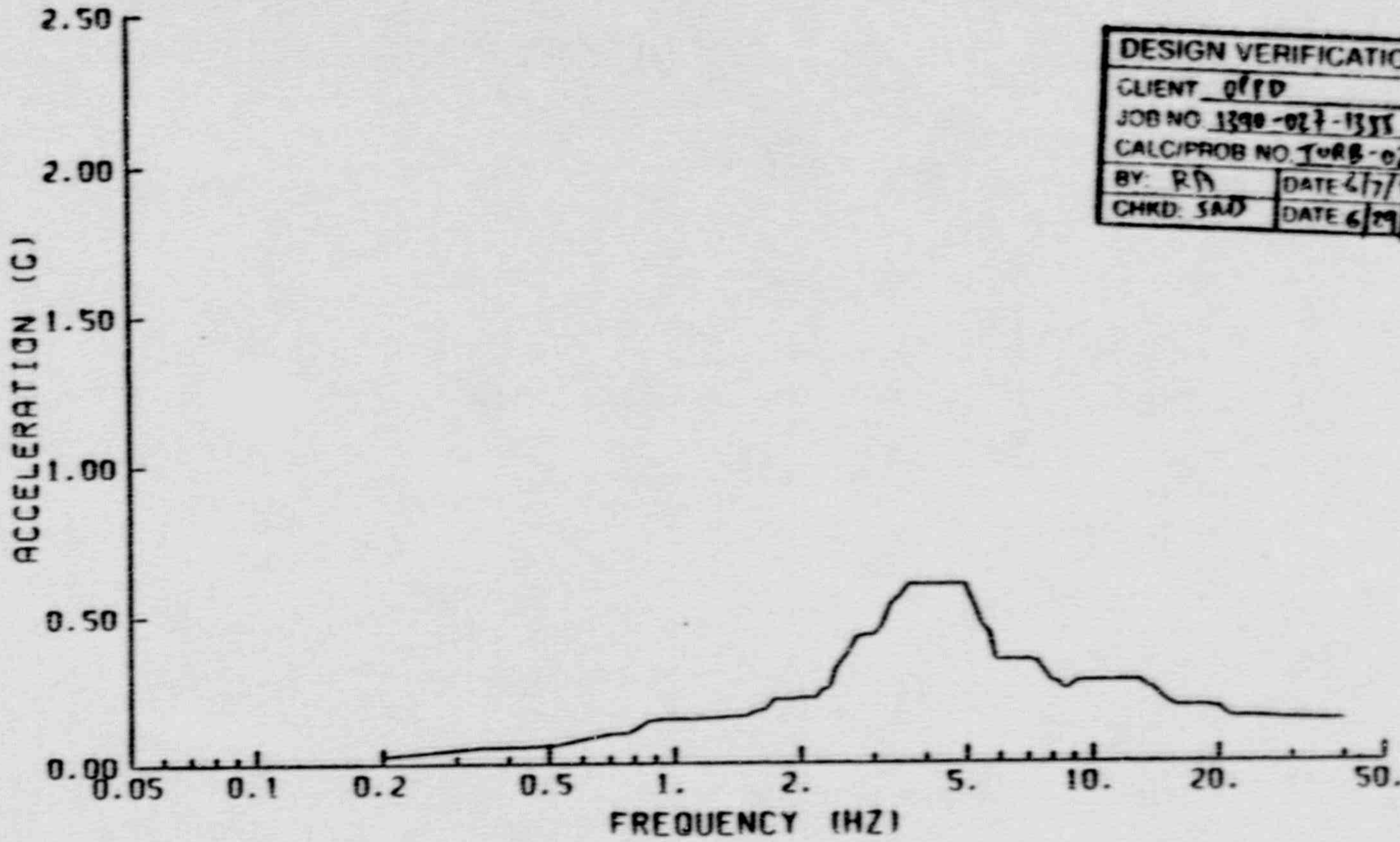
FIG. 6.16

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO 1390-027-1355	
CALC/PROB NO TURB-02	
BY: RA	DATE 6/7/88
CHKD SMD	DATE 6/29/88



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1011 FT-0 IN DIR.= VER
DAMPING = 2 PERCENT

FIG. 6.17

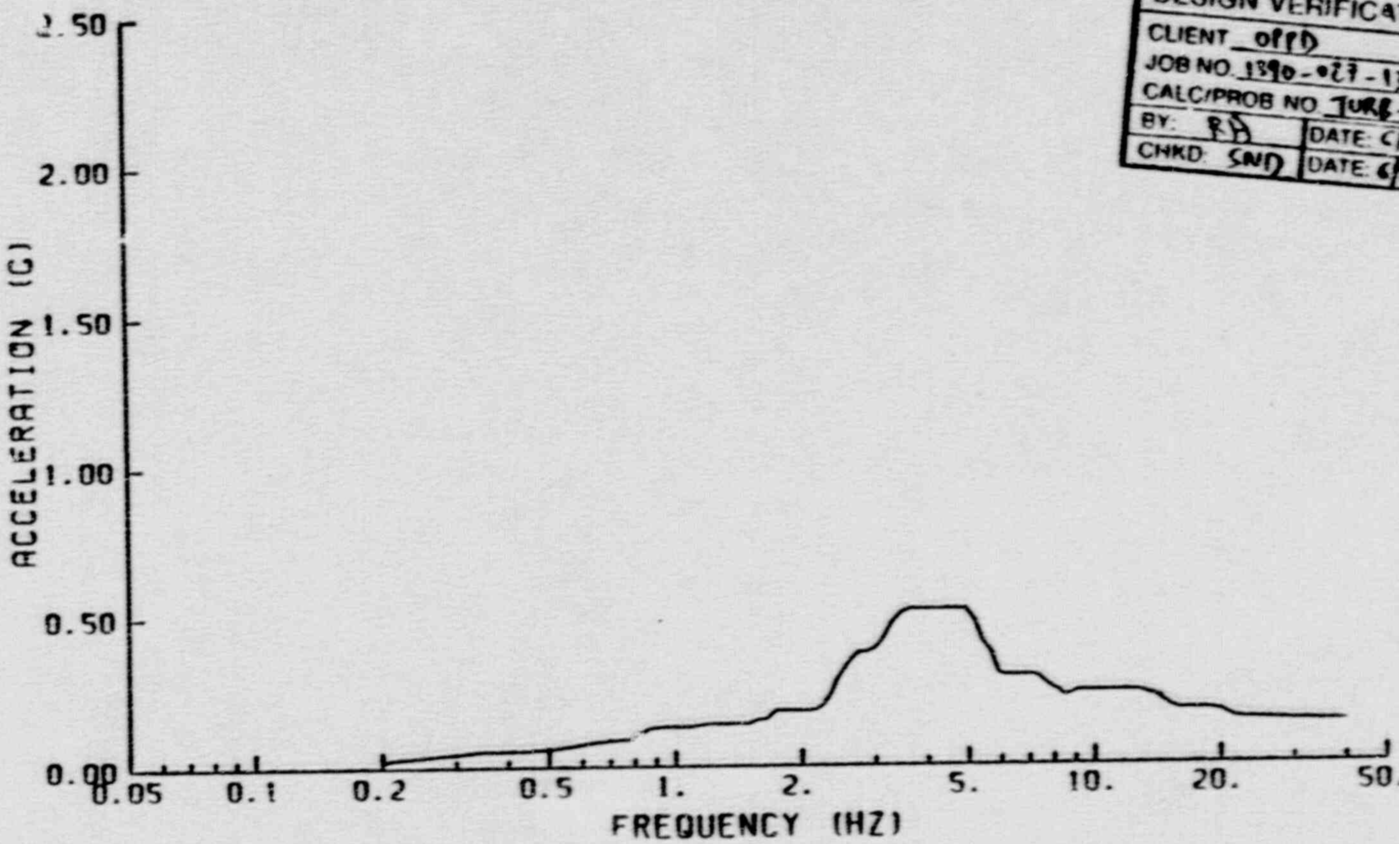


DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1355	
CALC/PROB NO. TURB-02	
BY: RM	DATE 6/7/88
CHKD: SAD	DATE 6/29/88

OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1011 FT-0 IN DIR.= VER
DAMPING = 5 PERCENT

FIG. 6.18

DESIGN VERIFICATION
CLIENT OPPD
JOB NO. 1390-027-1355
CALC/PROB NO. TURB-02
BY: RD DATE: 6/7/88
CHKD: SND DATE: 6/29/88



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV. = 1011 FT-0 IN DIR. = VER
DAMPING = 7 PERCENT

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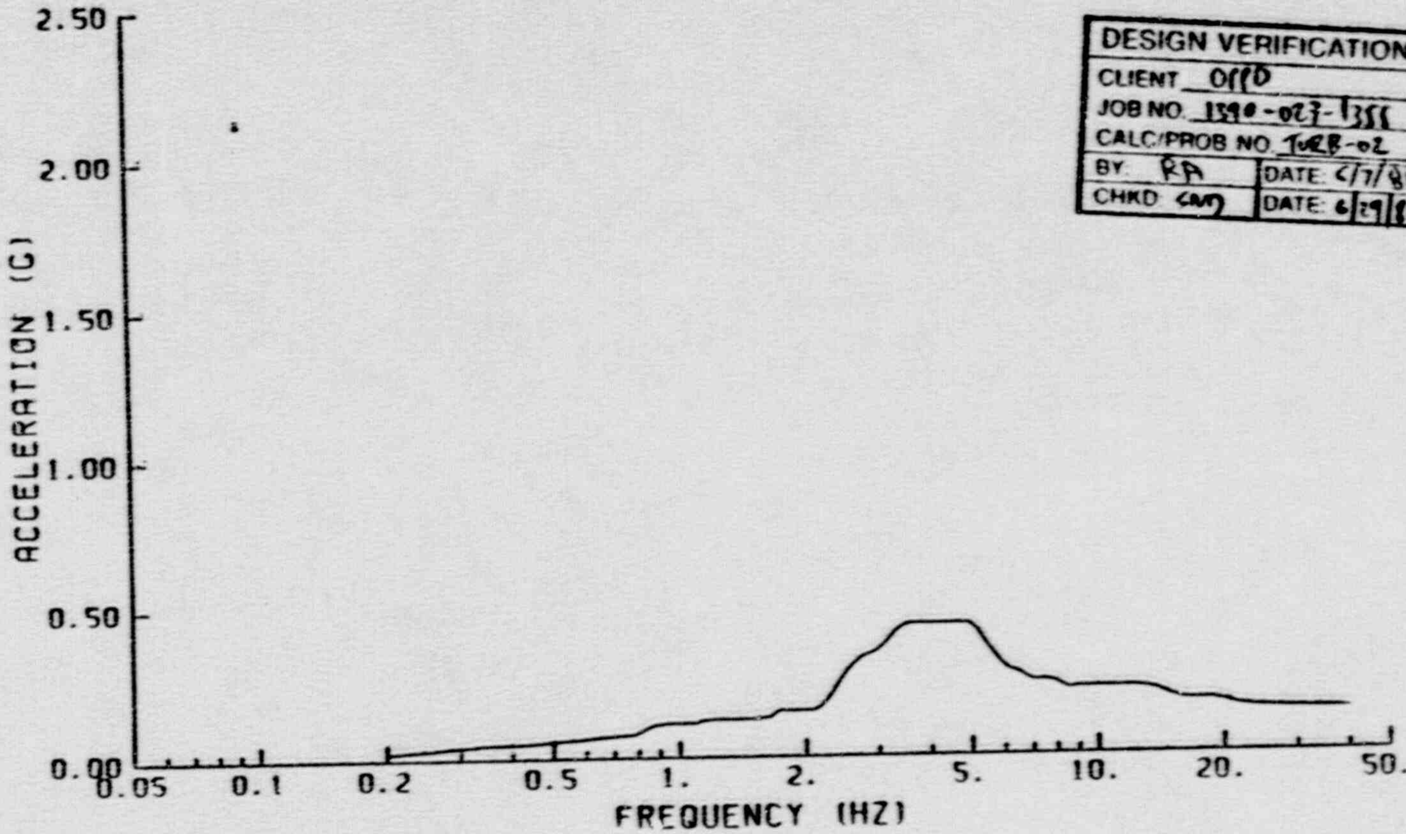
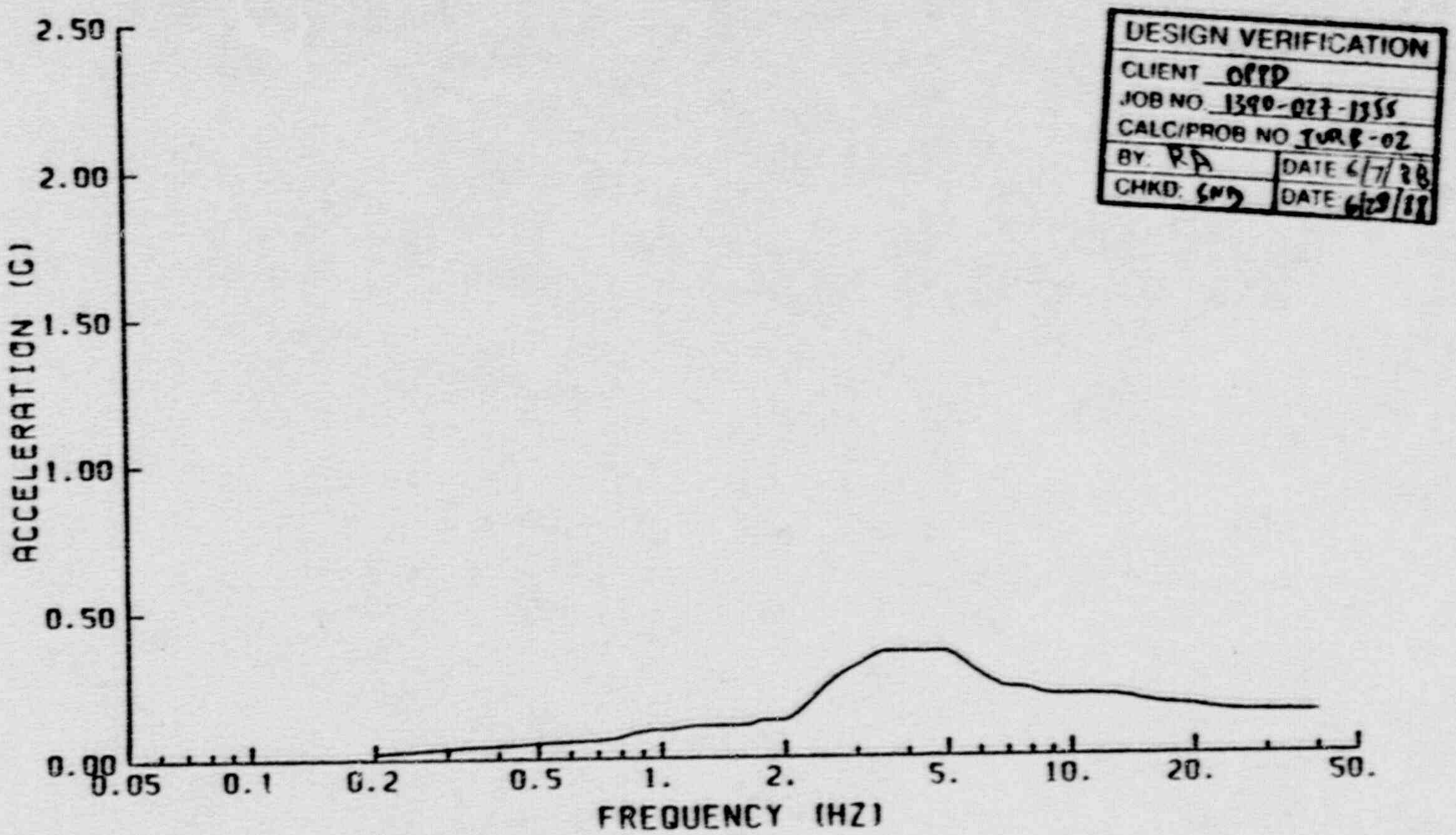
FIG. 6.19



DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-023-1355	
CALC/PROB NO. TURB-02	
BY: RA	DATE: 6/7/89
CHKD: SMP	DATE: 6/29/89

OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV. = 1011 FT-0 IN DIR. = VER
DAMPING =10 PERCENT

FIG. 6.20



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1011 FT-0 IN DIR.= VER
DAMPING =15 PERCENT

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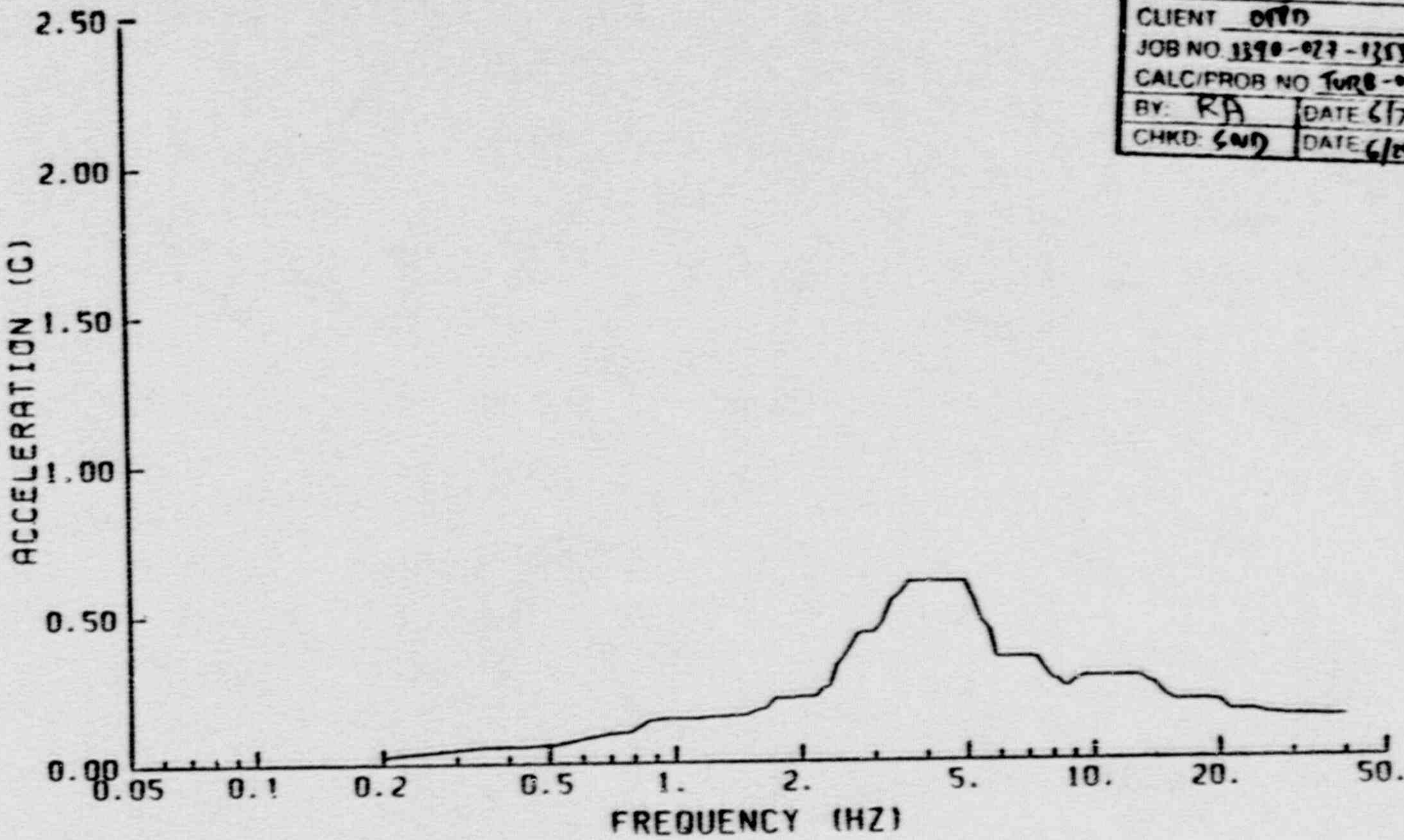
FIG. 6.21

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1355	
CALC/PROB NO. TURB-02	
BY: RA	DATE 6/7/88
CHKD: SND	DATE 6/29/88



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1011 FT-0 IN DIR.= VER
DAMPING = PVRC

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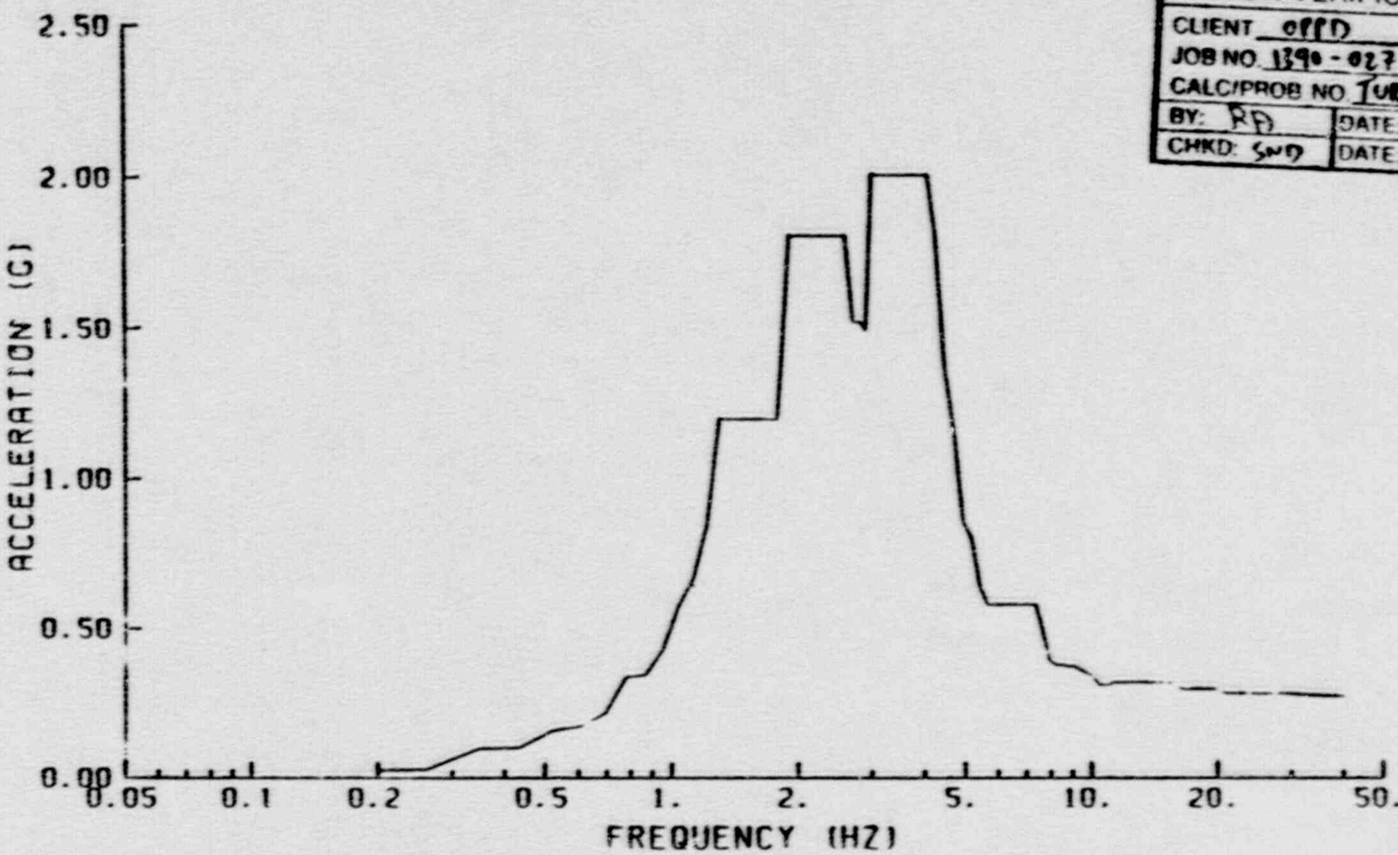
FIG. 6.22

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1355	
CALC/PROB NO. TURB-02	
BY: RD	DATE: 6/7/88
CHKD: SWD	DATE: 6/19/88



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV. = 1036 FT-0 IN DIR. = N-S
DAMPING = 2 PERCENT

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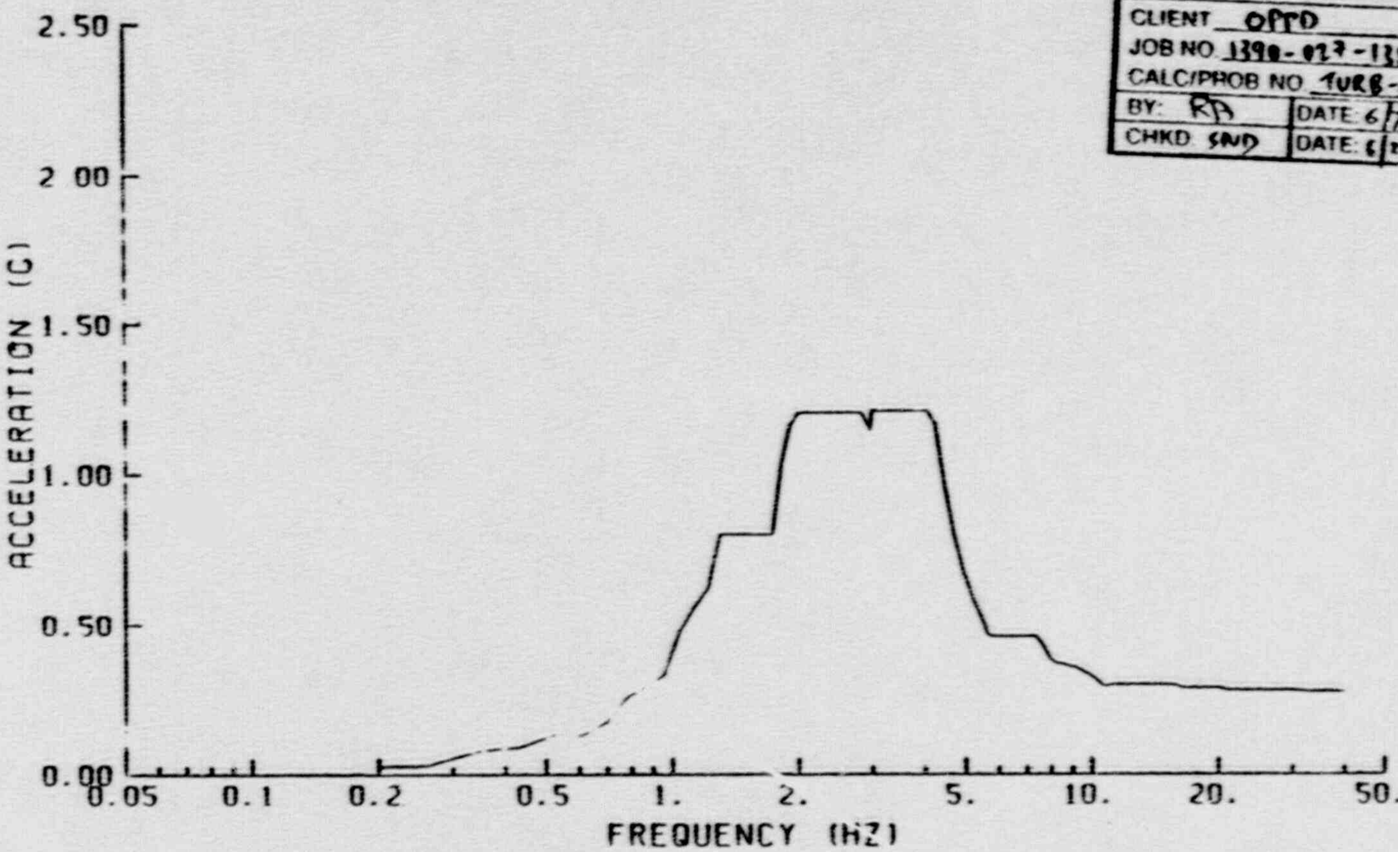
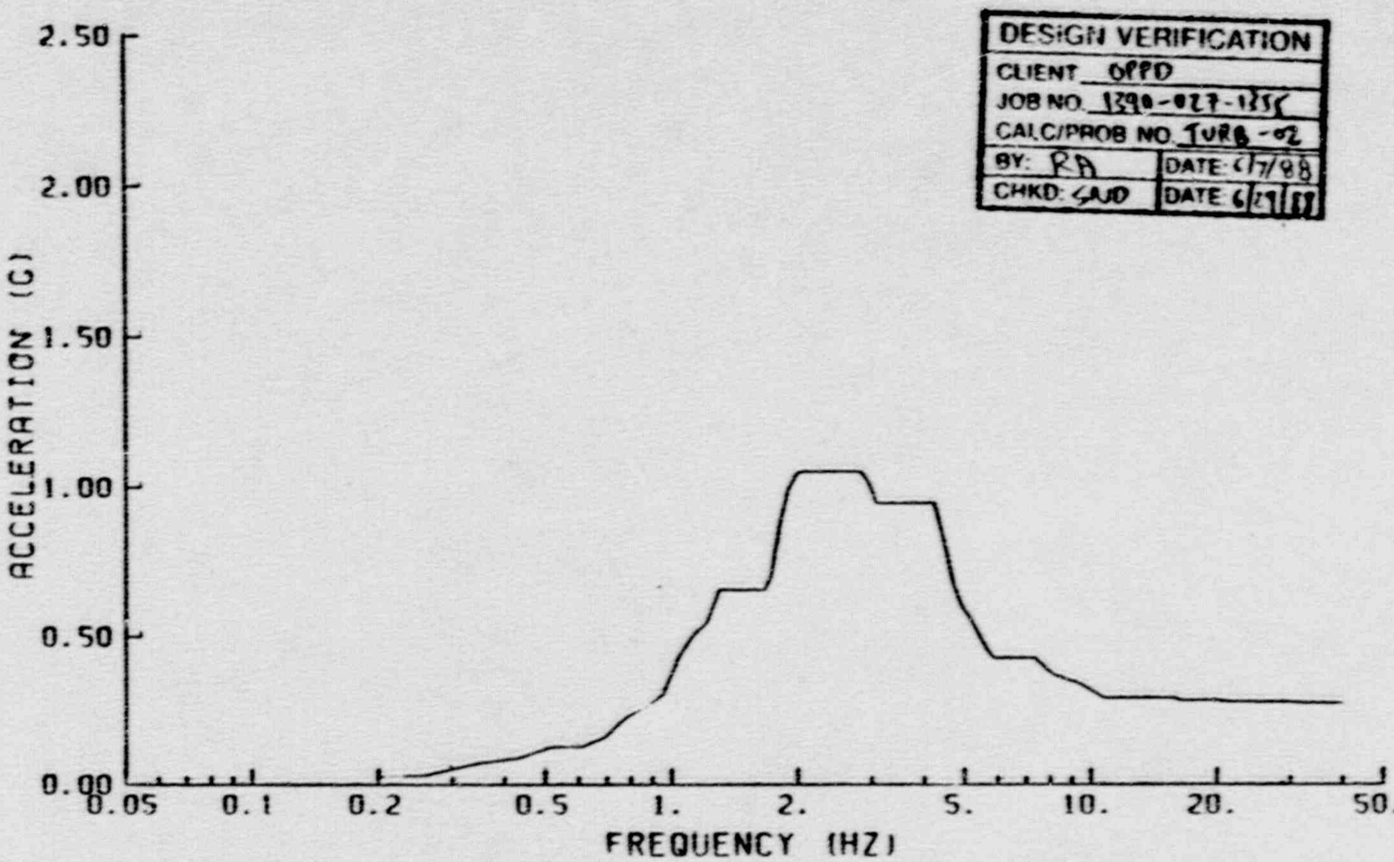
FIG. 6.23

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1355	
CALC/PROB NO. TURB-02	
BY: RA	DATE: 6/7/88
CHKD: SND	DATE: 6/29/88



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1036 FT-0 IN DIR.= N-S
DAMPING = 5 PERCENT

FIG C24



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1036 FT-0 IN DIR.= N-S
DAMPING = 7 PERCENT

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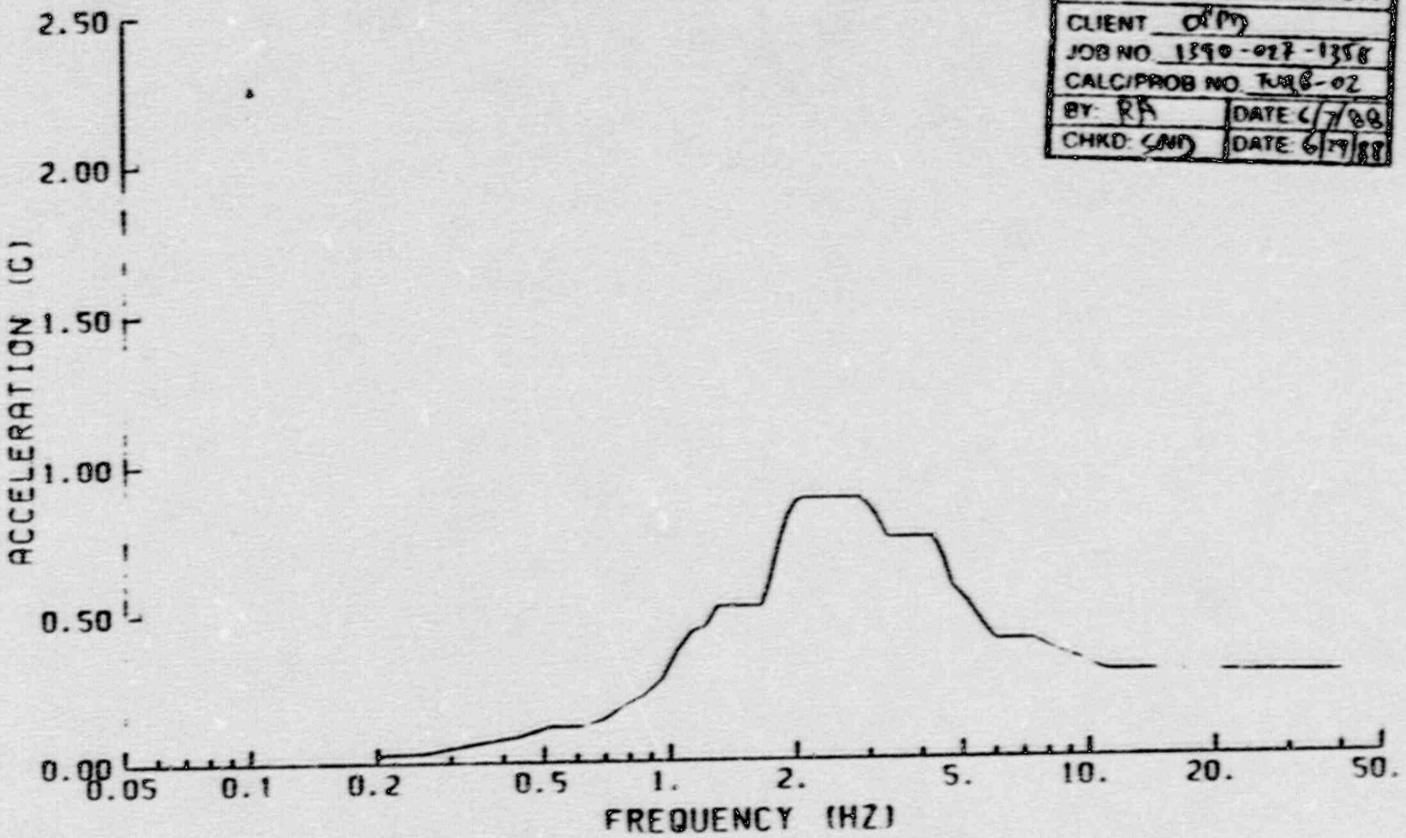
FIG. 6.25

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1358	
CALC/PROB NO. TURB-02	
BY: RA	DATE 6/7/88
CHKD: SMD	DATE 6/29/88



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1036 FT-0 IN DIR.= N-S
DAMPING =10 PERCENT

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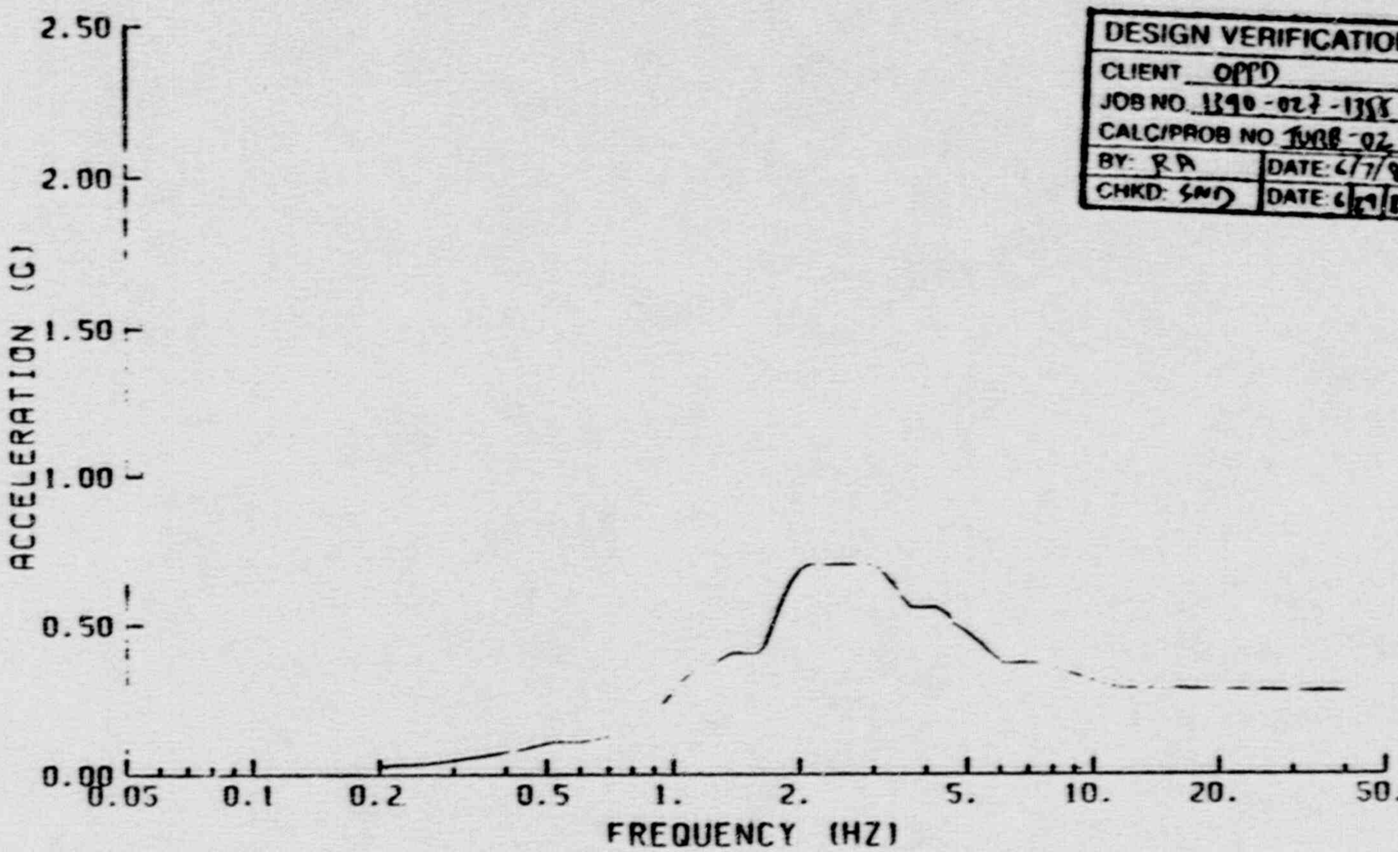
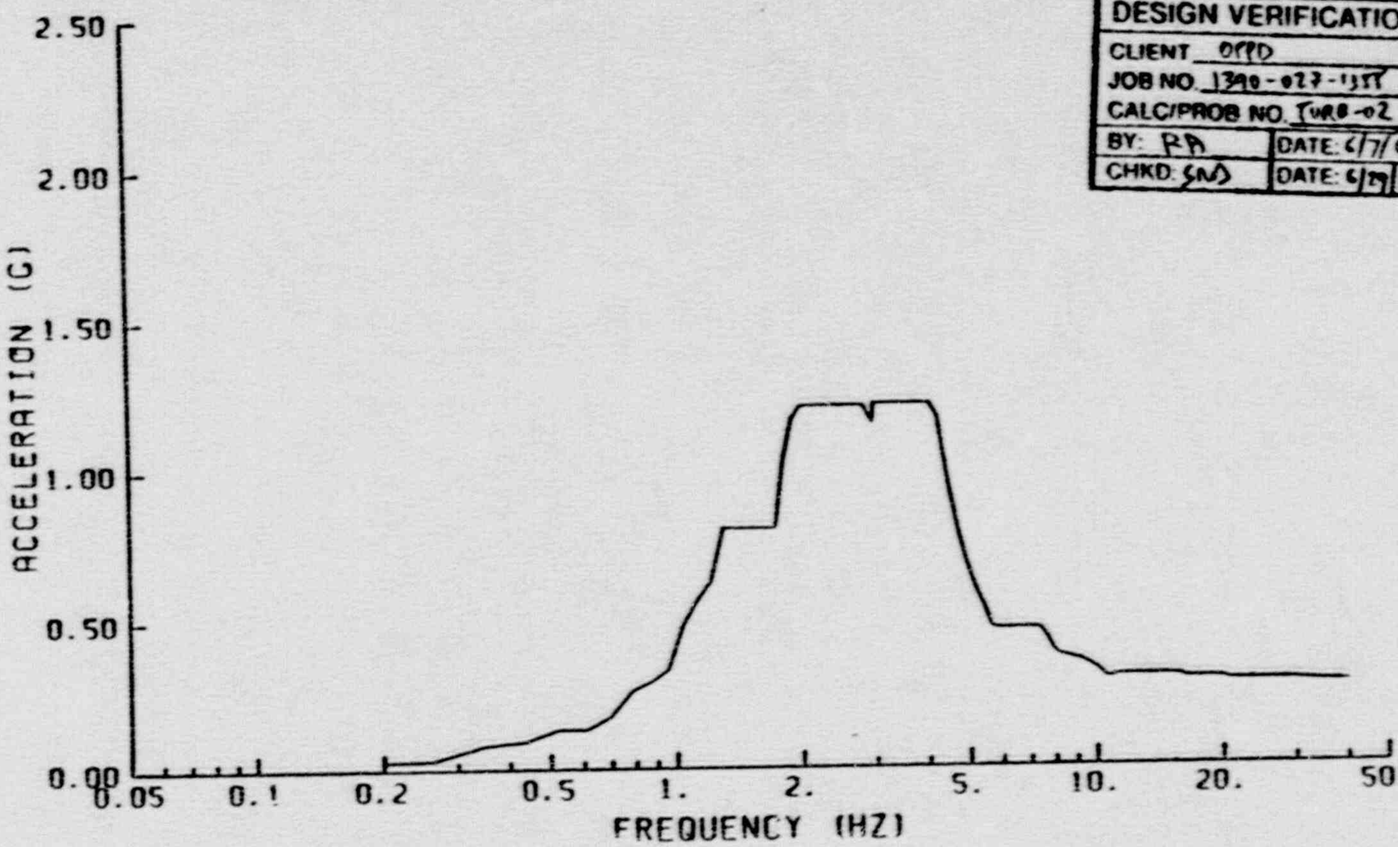
FIG. C.26



DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1358	
CALC/PROB NO TURB-02	
BY: RA	DATE: 6/7/88
CHKD: SWD	DATE: 6/29/88

OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1036 FT-0 IN DIR.= N-S
DAMPING =15 PERCENT

FIG. 6-27



DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1357	
CALC/PROB NO. TURB-02	
BY: RA	DATE: 6/7/88
CHKD: SNS	DATE: 6/29/88

OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV. = 1036 FT-0 IN DIR. = N-S
DAMPING = PVRC

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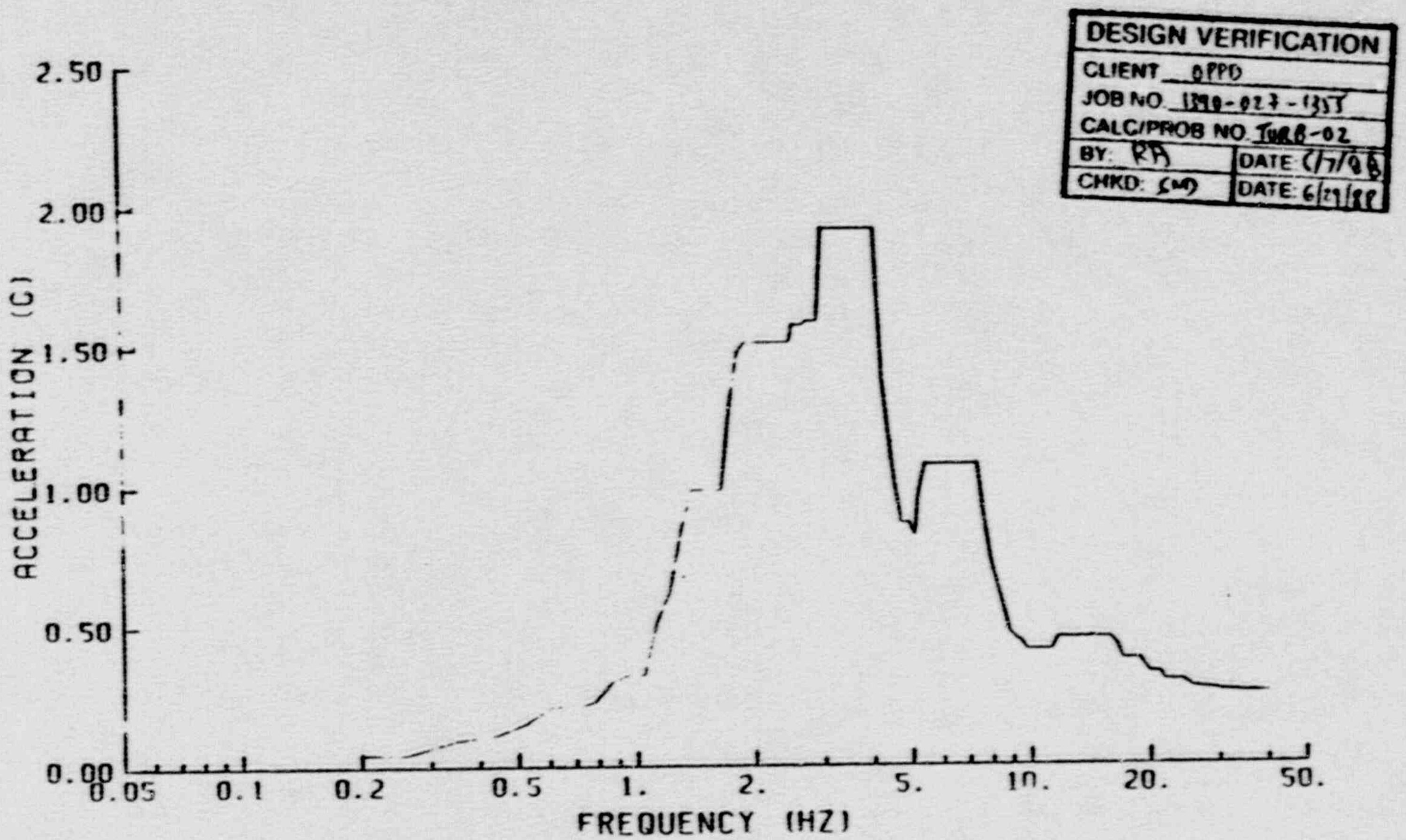
FIG. 6.28



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1036 FT-0 IN DIR.= E-W
DAMPING = 2 PERCENT

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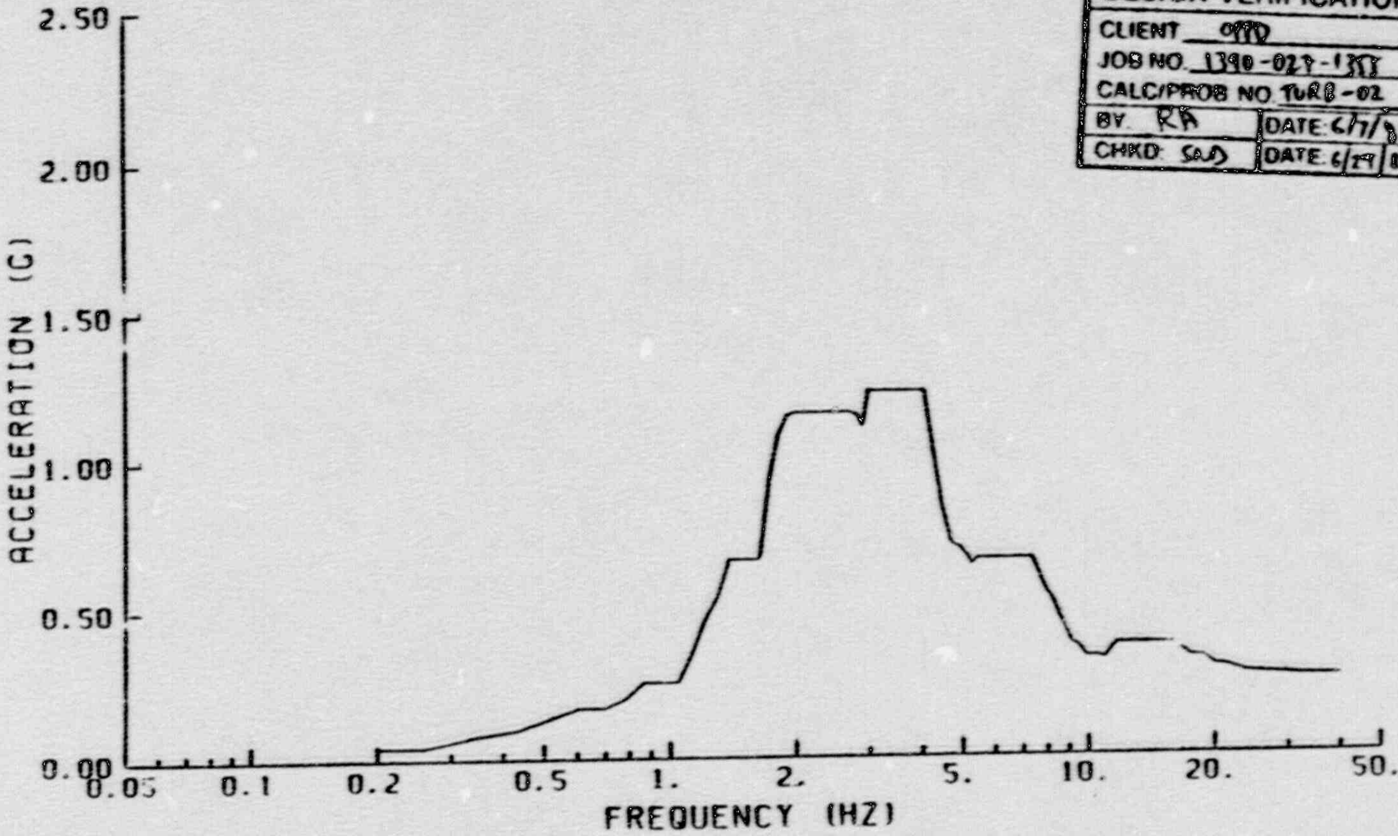
FIG. 6.29

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1353	
CALC/PROB NO. TURB-02	
BY: RA	DATE: 6/7/88
CHKD: SAD	DATE: 6/29/88



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV. = 1036 FT-0 IN DIR. = E-W
DAMPING = 5 PERCENT

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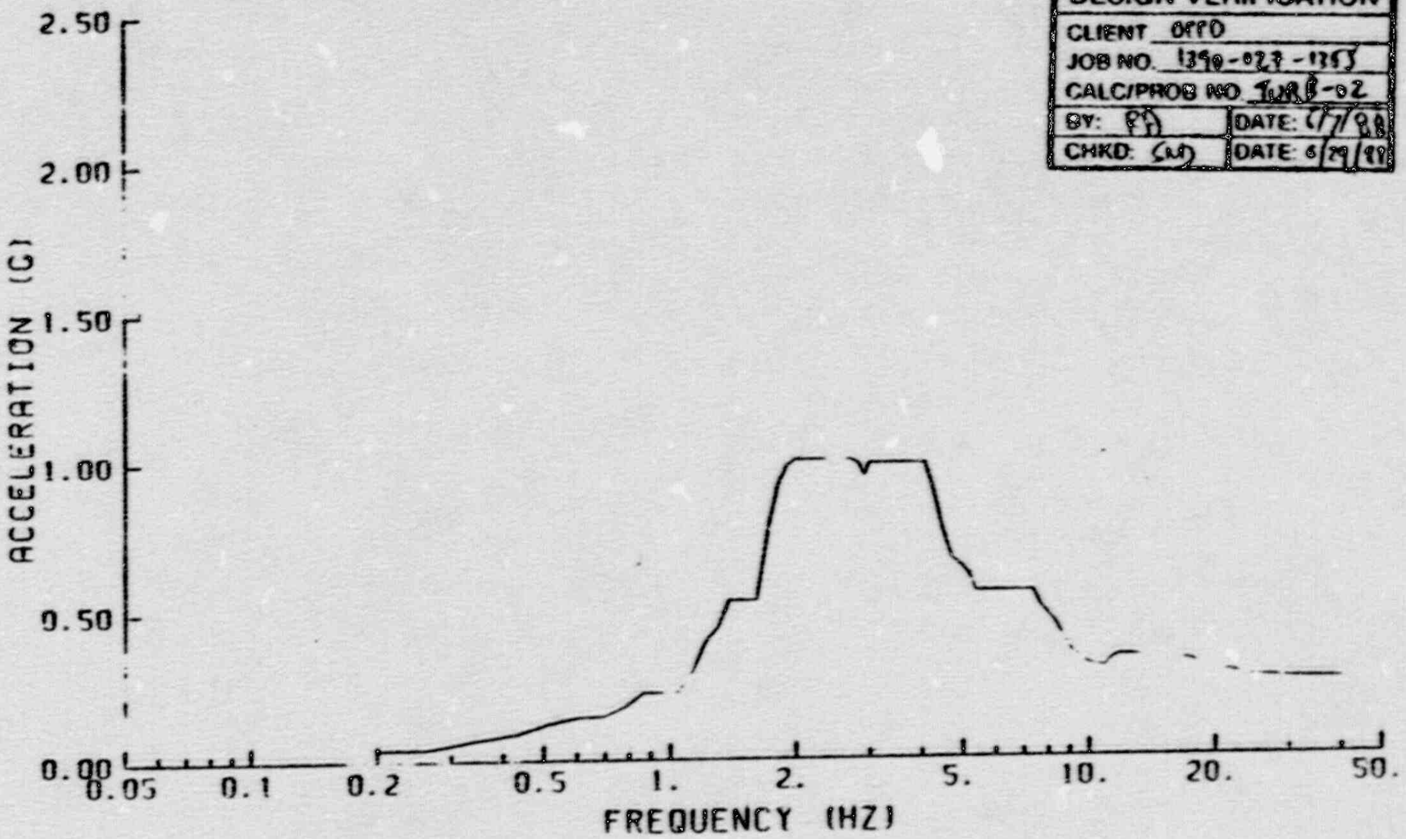
FIG. 6.30

DESIGN VERIFICATION

CLIENT OPPD	
JOB NO. 1390-027-1353	
CALC/PROB NO. TURB-02	
BY: [illegible]	DATE: 6/7/88
CHKD: [illegible]	DATE: 6/29/88



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV. = 1036 FT-0 IN DIR. = E-W
DAMPING = 7 PERCENT

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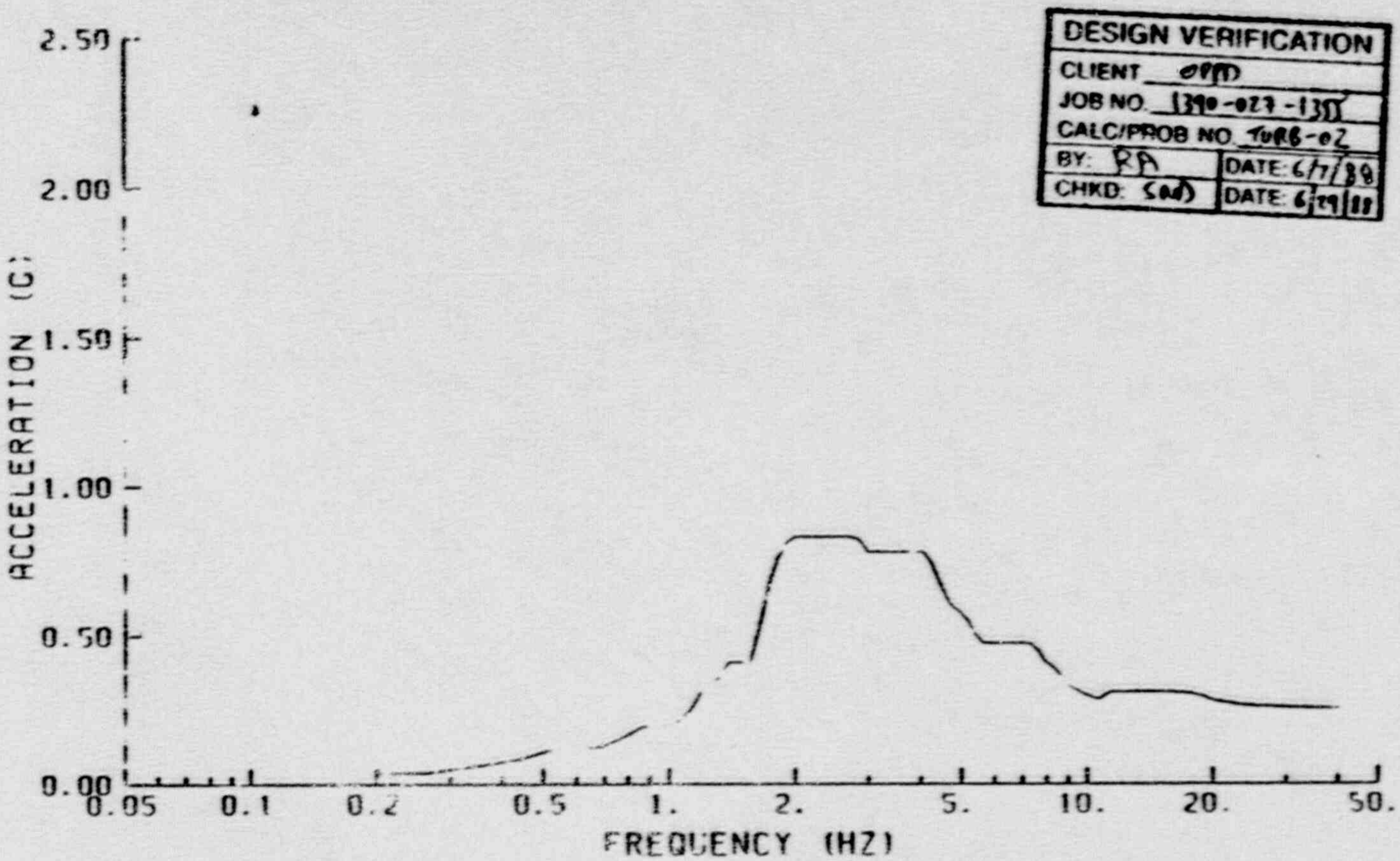
FIG. 6.31



DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1355	
CALC/PROB NO. TURB-02	
BY: RA	DATE: 6/7/88
CHKD: SAD	DATE: 6/29/88

OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE   ELEV.= 1036 FT-0 IN   DIR.= E-W
DAMPING =10 PERCENT

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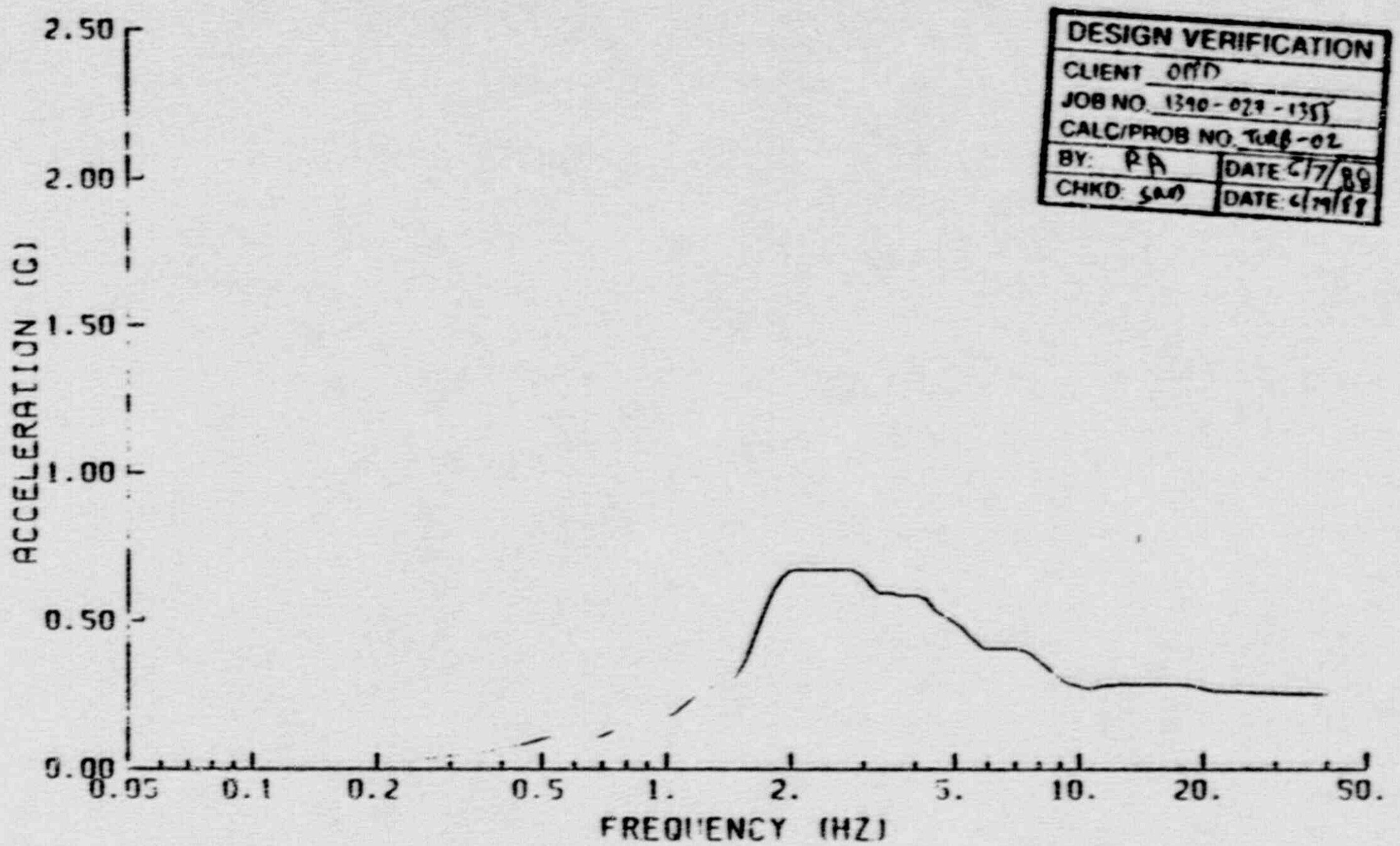
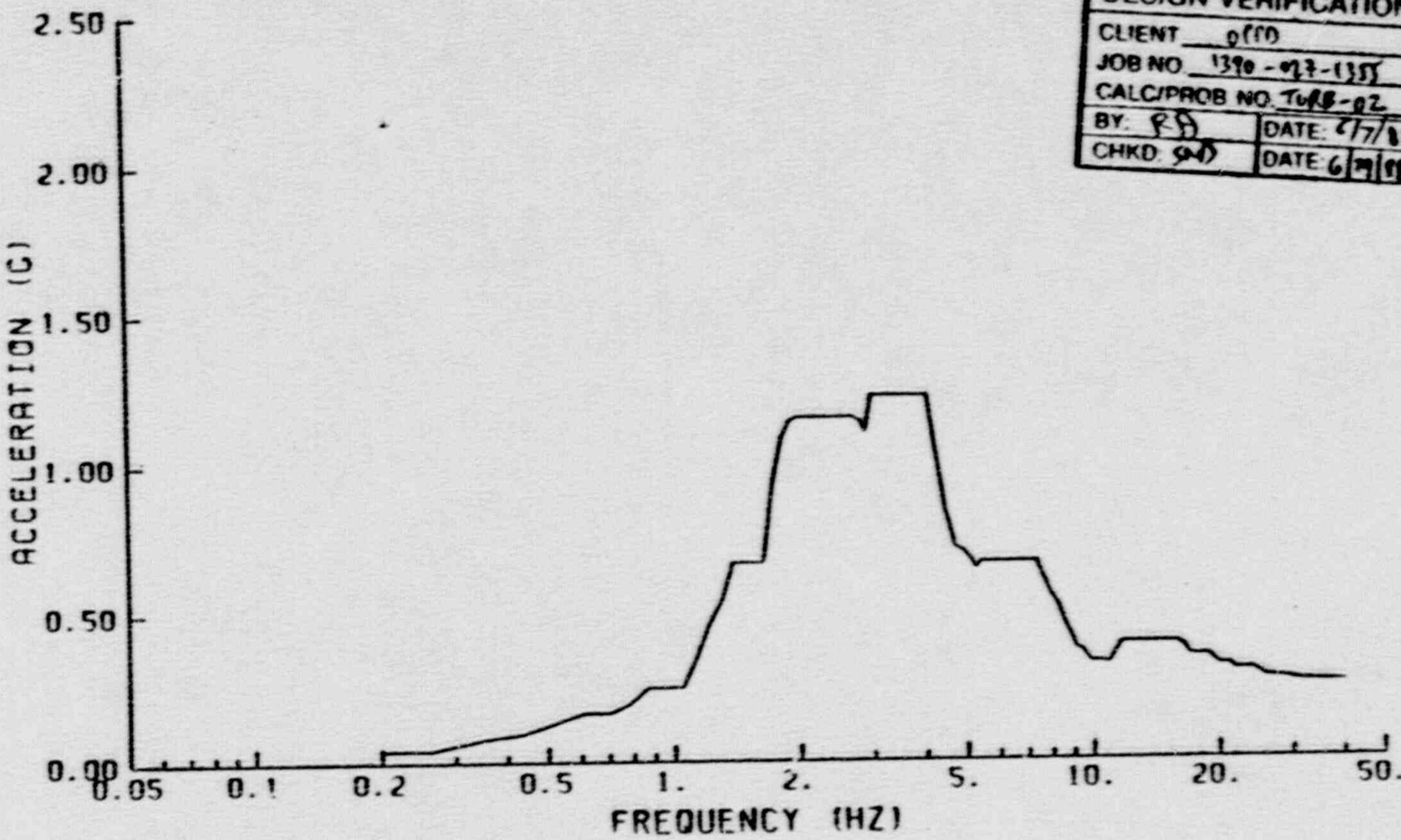
FIG. 6.32



DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-029-1355	
CALC/PROB NO. TURB-02	
BY: RA	DATE 6/7/89
CHKD: SAM	DATE 6/19/89

OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV. = 1035 FT-0 IN DIR. = E-W
DAMPING = 15 PERCENT

FIG. 6.33



DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1355	
CALC/PROB NO. TURB-02	
BY: RD	DATE: 6/7/88
CHKD: SND	DATE: 6/9/88

OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1036 FT-0 IN DIR.= E-W
DAMPING = PVRC

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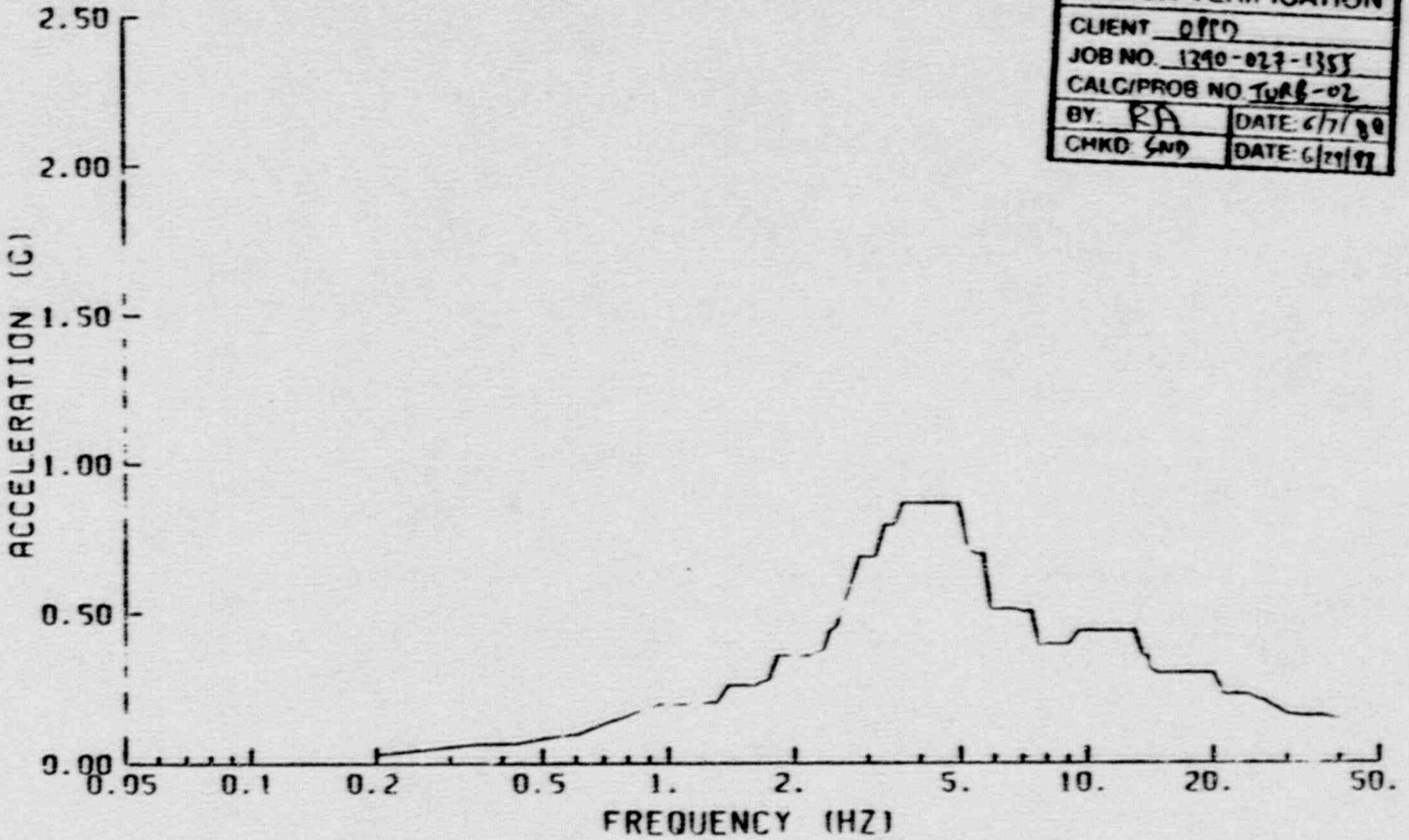
FIG. 6.34

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1353	
CALC/PROB NO. TURB-02	
BY: RA	DATE: 6/7/89
CHKD: SND	DATE: 6/29/89



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1036 FT-0 IN DIR.= VER
DAMPING = 2 PERCENT

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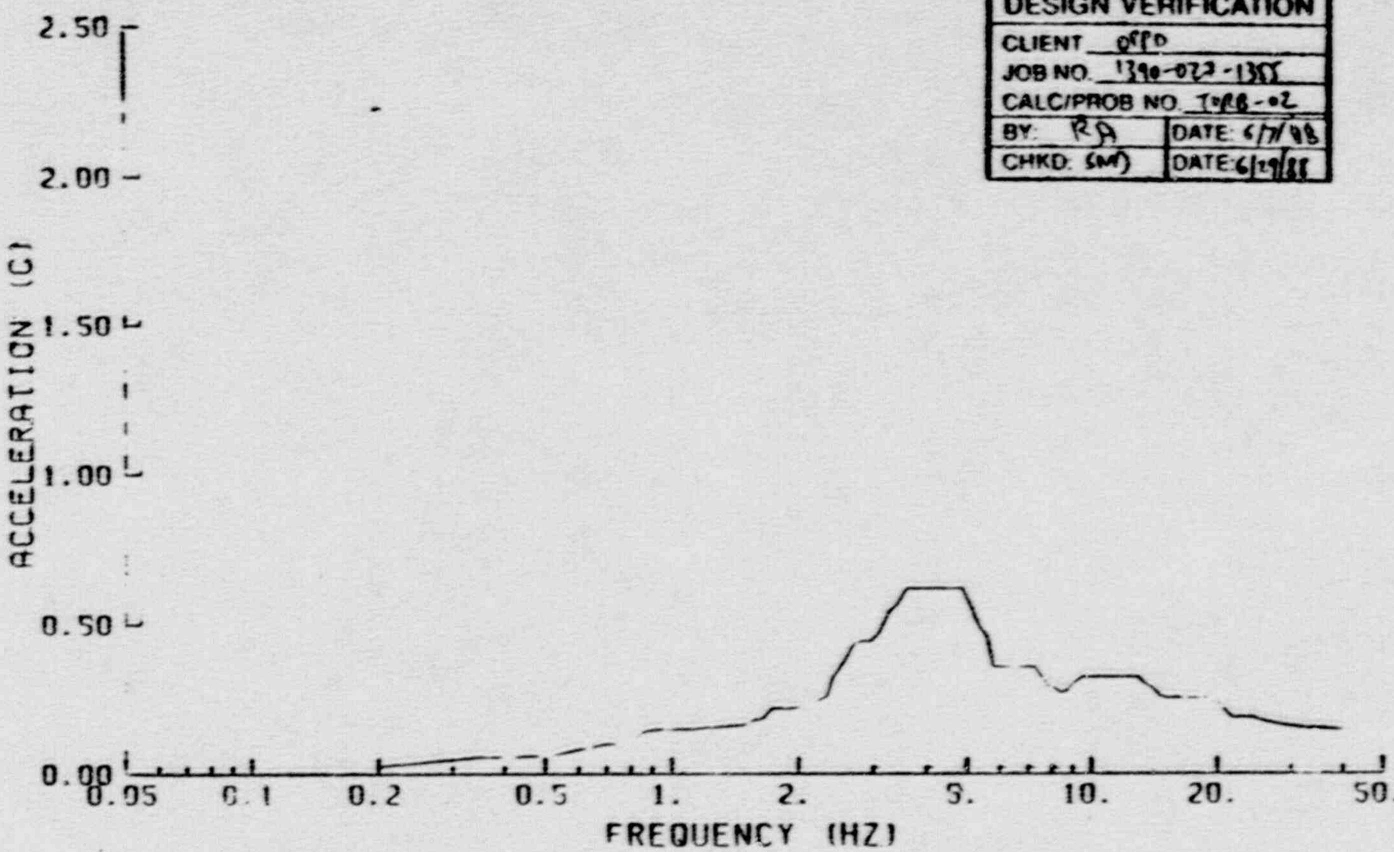
FIG. 6.35

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-023-1355	
CALC/PROB NO. TURB-02	
BY: RA	DATE: 6/7/88
CHKD: SMJ	DATE: 6/29/88



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1036 FT-0 IN DIR.= VER
DAMPING = 5 PERCENT

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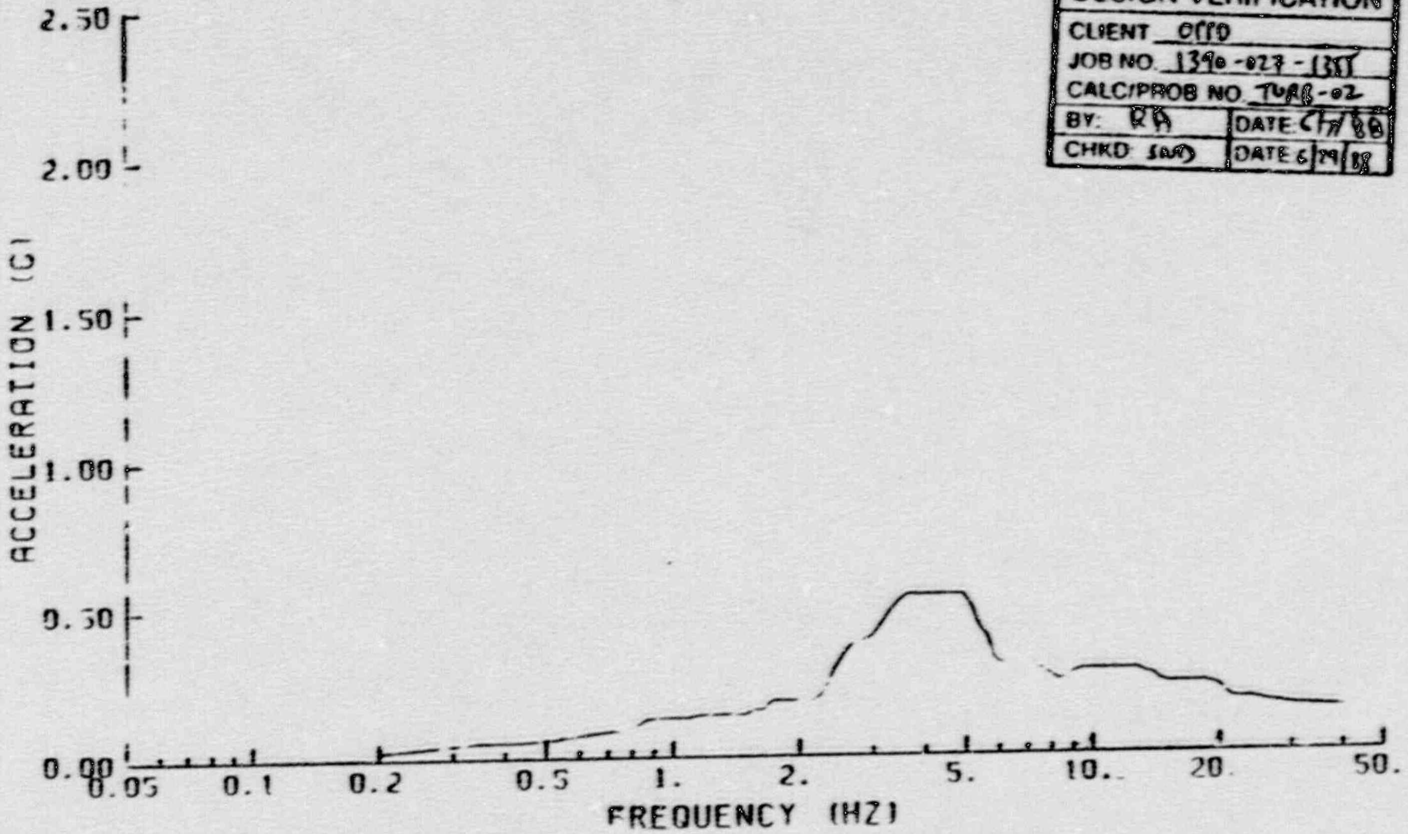
FIG. 6.36

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1351	
CALC/PROB NO. TURB-02	
BY: RA	DATE 6/7/88
CHKD SWD	DATE 6/29/88



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV. = 1036 FT-0 IN DIR. = VER
DAMPING = 7 PERCENT

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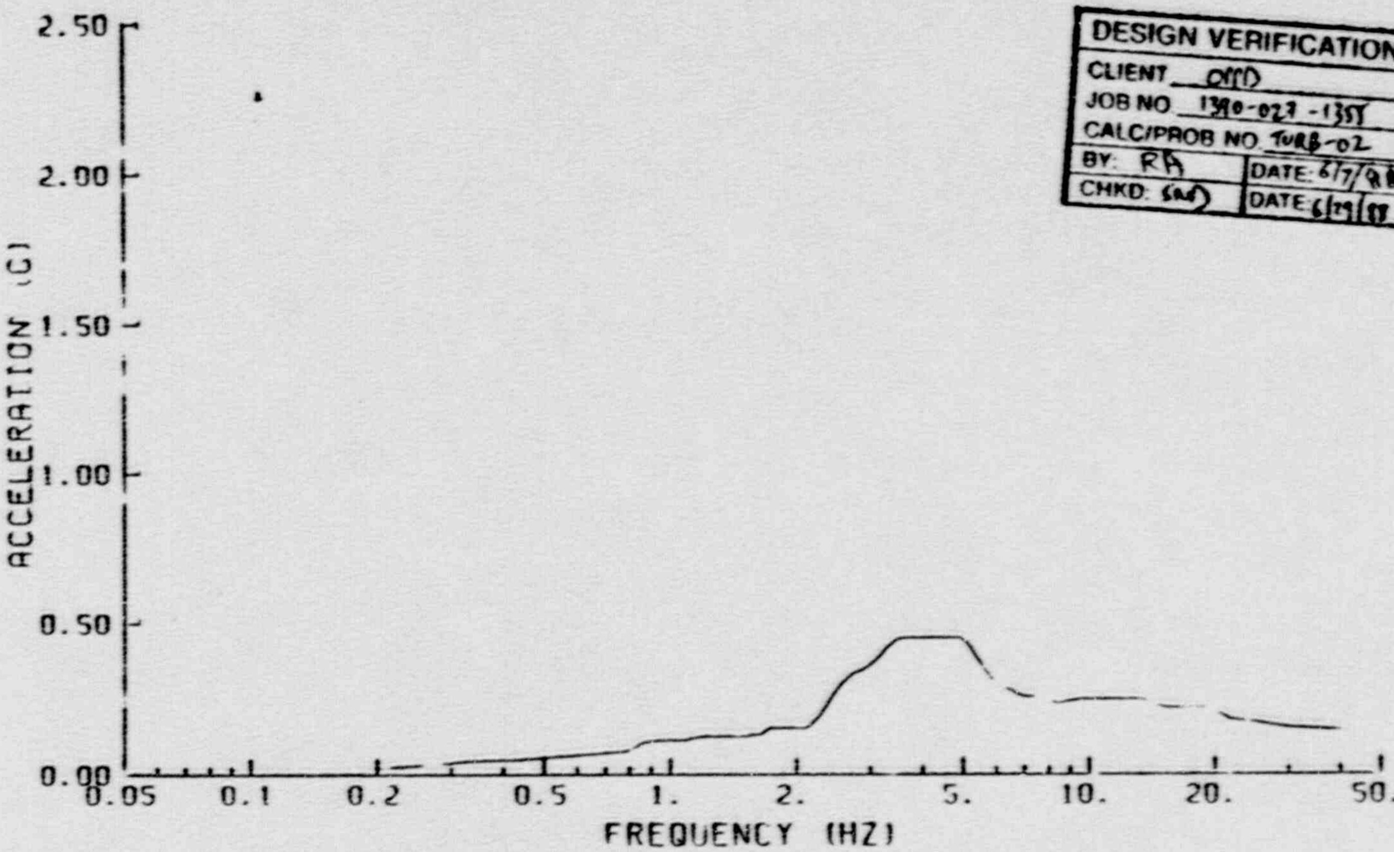
FIG. 6.37



DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1355	
CALC/PROB NO. TURB-02	
BY: RA	DATE: 6/7/88
CHKD: SAS	DATE: 6/29/88

OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV. = 1035 FT-0 IN DIR. = VER
DAMPING =10 PERCENT

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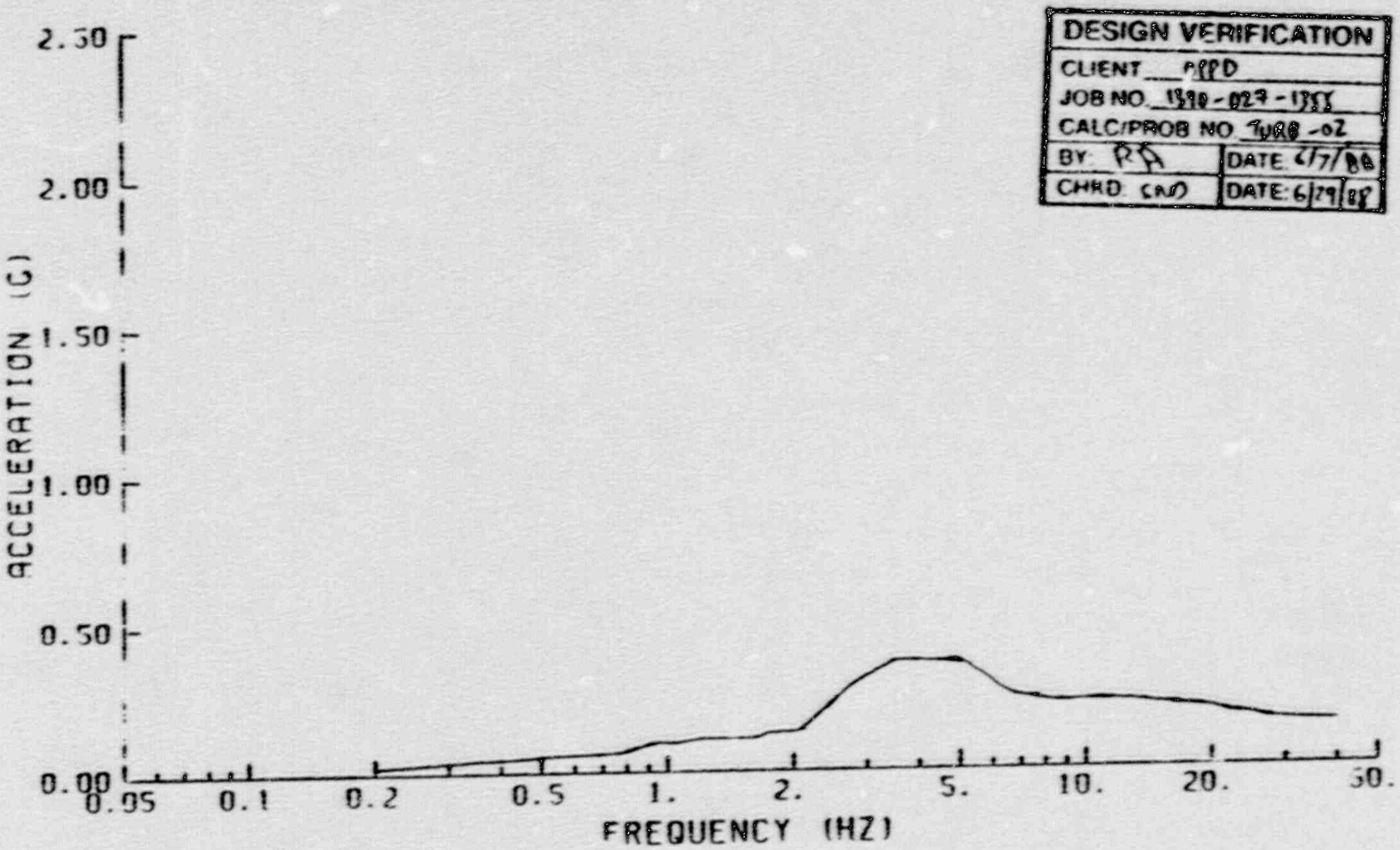
FIG. 6.38



DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1355	
CALC/PROB NO. TURB-02	
BY: RA	DATE: 6/7/88
CHKD: CND	DATE: 6/29/88

OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV.= 1036 FT-0 IN DIR.= VER
DAMPING =15 PERCENT

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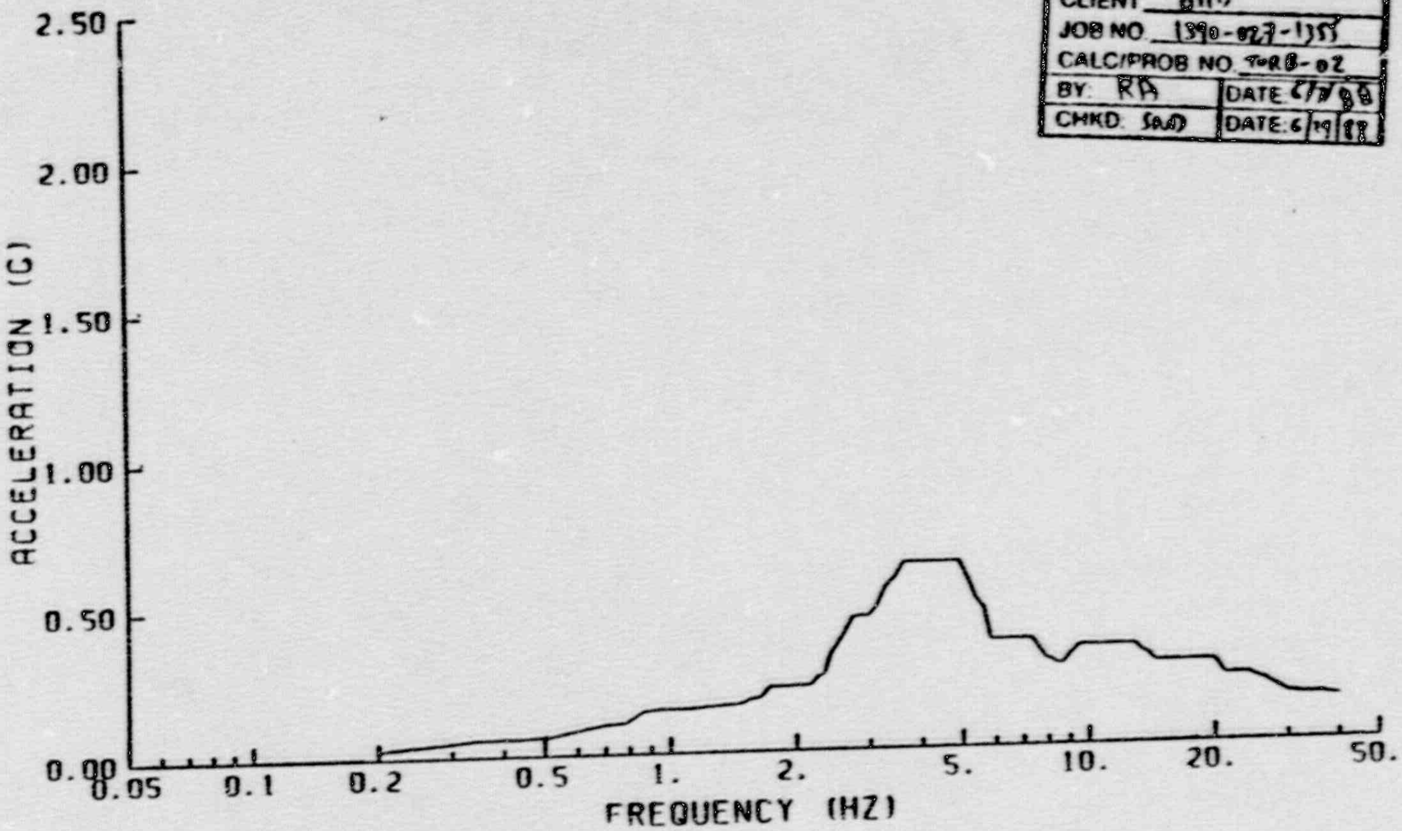
FIG. 6.39

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1355	
CALC/PROB NO. TURB-02	
BY: RA	DATE: 6/7/88
CHKD: SAD	DATE: 6/19/88



OPPD/FT. CALHOUN UNIT 1, DESIGN FLOOR RESPONSE SPECTRUM
BUILDING = TURBINE ELEV. = 1036 FT-0 IN DIR. = VER
DAMPING = PVRC

7. SEISMIC ANCHOR MOVEMENTS WITHIN TURBINE + OFFICE BUILDINGS

The Turbine and office buildings together are modeled as one stick. Therefore, the SAMs for the two buildings are the same.

Maximum relative displacements for various floor with respect to base for turbine + office buildings are given in Table 7.1.

Maximum relative displacements at elevation 1036' for turbine generator foundation with respect to base are given in Table 7.2.

Maximum relative displacements between two consecutive floors (floor drifts) are given in Table 7.3 for Turbine + office Buildings.

Relative displacement between two consecutive floors is not calculated for turbine generator foundation, as the maximum displacement

relative to base at top of foundation (1036') is negligible. However, SAM for T.G. foundation (in Table 7.5) are calculated, assuming a straight line vibration shape.

SAM for turbine + office building are given in Table 7.4.

NOTE: Acceleration time histories at center of mass are used to calculate maximum relative displacements, and hence SAM.

TABLE 7.1

TURBINE + OFFICE BUILDINGS

MAXIMUM DISPLACEMENT RELATIVE TO BASE, SSE Event
CBL # TURB-02-24 to TURB-02-33

ELEVATION (FT)	|MAXIMUM DISPLACEMENT| N-S (FT)	N-S (IN)	E-W FT	E-W (IN)	VER. (FT)	VER. (IN)
1011'	0.1684×10^{-2}	0.020	0.1304×10^{-2}	0.016	0.2216×10^{-2}	0.027
1036'	0.2822×10^{-1}	0.339	0.1066×10^{-1}	0.128	0.1761×10^{-2}	0.021
1051'	0.2419×10^{-1}	0.290	0.7477×10^{-2}	0.090	0.2874×10^{-2}	0.034
1073.5'	0.1422	1.71	0.1685×10^{-1}	0.202	0.7196×10^{-3}	0.009
1092.9'	0.2266	2.72	0.134×10^{-1}	0.161	0.5403×10^{-3}	0.006

TABLE 7.2

TURBINE GENERATOR FOUNDATION, SSE, Event

CBSL # TURB-02-42 & TURB-02-43

ELEVATION (FT)	|MAXIMUM DISPLACEMENT| REL. TO BASE N-S (FT)	N-S (IN)	E-W (FT)	E-W (IN)	VER. (FT)	VER. (IN)
1036'	0.9873×10^{-3}	0.012	0.2641×10^{-2}	0.032	0.4910×10^{-3}	0.006

REV	BY	DATE	CHECKED	DATE
0	RA	6/7/88	SRD	7/5/88

IMPELL CORPORATION

JOB NO 1310-027-1355
CALC NO TURB-02

TABLE 7.3

TURBINE + OFFICE BUILDINGS

MAXIMUM FLOOR DRIFT

SSE EVENT

CBSL # TURB-02-34 TO TURB-02-43
TURB-02-24 & TURB-02-25

FLOOR ELEVATION RANGE (FT)	|MAXIMUM FLOOR DRIFT|					
	N-S		E-W		VER	
	(FT)	(IN)	(FT)	(IN)	(FT)	(IN)
1011'-990'	0.1684×10^{-2}	0.020	0.1304×10^{-2}	0.016	0.2216×10^{-2}	0.027
1036'-1011'	0.2763×10^{-1}	0.332	0.1075×10^{-1}	0.129	0.4586×10^{-3}	0.006
1051'-1036'	0.7234×10^{-2}	0.087	0.5512×10^{-2}	0.066	0.1116×10^{-2}	0.013
1073.5'-1051'	0.1315	1.578	0.1738×10^{-1}	0.209	0.2809×10^{-2}	0.034
1092.9'-1073.5'	0.8630×10^{-1}	1.036	0.1711×10^{-1}	0.205	0.6359×10^{-3}	0.008

REV	BY	DATE	CHECKED	DATE
0	RA	6/7/88	SAD	7/5/88

IMPELL CORPORATION

JOB NO 1390-027-1355

CALC NO TURB-02

TABLE 7.4

SEISMIC ANCHOR MOVEMENTS (IN INCHES)

TURBINE + OFFICE BUILDINGS, SSE EVENT

	BASE			1011'			1036'			1051.0'			1073.5'			1092.9'		
				N-S	E-W	V	N-S	E-W	V	N-S	E-W	V	N-S	E-W	V	N-S	E-W	V
BASE				0.020	0.016	0.027	0.339	0.128	0.021	0.290	0.090	0.034	1.71	0.202	0.009	2.72	0.161	0.006
1011'							0.332	0.129	0.006	0.310	0.106	0.046	1.73	0.218	0.036	2.74	0.177	0.033
1036'										0.087	0.066	0.013	1.665	0.275	0.030	2.701	0.289	0.027
1051'	S	Y	M	M	E	T	R	I	C	A	L		1.578	0.204	0.034	2.614	0.251	0.040
1073.5'																1.036	0.205	0.008
1092.9'																		

REV	BY	DATE	CHECKED	DATE
0	RA	6/7/88	SND	7/3/88

IMPELL CORPORATION

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TABLE 75

SEISMIC ANCHOR MOVEMENTS (IN INCHES)

TURBINE GENERATOR FOUNDATION

SSE EVENT

	BASE (990')	1011' *			1036'		
		N-S	E-W	V	N-S	E-W	V
BASE (990')		0.005	0.015	0.003	0.012	0.032	0.006
1011'	SYMMETRICAL				0.007	0.017	0.003
1036'							

* Linearly interpolated between base and 1036'.

REV	BY	DATE	CHECKED	DATE
0	RA	6/7/88	GMM	7/5/88

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JOB NO 1390-027-1355

CALC NO TURB-02

8. SEISMIC ANCHOR MOVEMENTS BETWEEN TURBINE AND AUXILIARY BUILDINGS

The Seismic anchor movements between the Turbine and Auxiliary buildings are calculated using the methodology described in Section 2.2.5. In brief, SAM between a floor of the turbine building and a floor of the Auxiliary building is calculated as follows:

$$(S_{ij})_{ta} = |\Delta_{bt,ba}| + |\Delta_{bt,it}| + |\Delta_{ba,ja}|$$

where

$(S_{ij})_{ta}$ = SAM between floor i of Turbine building and floor j of Auxiliary building

$\Delta_{bt,ba}$ = Maximum relative displacement between Turbine base and Auxiliary base

$\Delta_{bt,it}$ = Maximum relative displacement between Turbine base and floor i of Turbine building

0	RA	6/8/89	SND	6/29/89	IMPELL CORPORATION
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JOB NO 1390-027-1355

CALC NO TURB-02

$\Delta_{ba\,ja}$ = Maximum relative displacement between Auxiliary base and floor j of Auxiliary Building.

$\Delta_{bt\,ba}$ is as follows.

CRL # TURB-02-44 & TURB-02-45

MAXIMUM RELATIVE DISPLACEMENT BETWEEN TURBINE BASE AND AUXILIARY BASE

SSE EVENT

N-S		E-W		VER	
(FT)	(IN)	(FT)	(IN)	(FT)	(IN)
0.1719×10^{-1}	0.206	0.1509×10^{-1}	0.181	0.2617×10^{-2}	0.031

SAM is calculated only between elevation 1036' of Turbine and Auxiliary Buildings.

$$S_{a1\,3a} = \begin{cases} 0.206 + 0.339 + 0.026 = 0.571'' \text{ in N-S} \\ 0.181 + 0.128 + 0.030 = 0.339'' \text{ in E-W} \\ 0.031 + 0.021 + 0.007 = 0.059'' \text{ in VER} \end{cases}$$

REV	BY	DATE	CHECKED	DATE
0	RA	6/9/88	SMD	9/1/88

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JOB NO 1310-027-1355

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9. PERMANENT FILES

9.1 DESIGN SPECTRA

Following files are saved on VSN Tape # 017880.

FILE NAME	DESCRIPTION
RTURBGL	Input file for GLAYER/CLASSI
RTURBG1	TAPE1 from GLAYER/CLASSI
RTURBCF	Input file for CLAF/CLASSI
RTURCF1	TAPE10 from CLAF/CLASSI
RTURMOD	Input file for EDSGAP.
TB4TAPE	Outfile from EDSGAP.
RTURNOD	Nodal coordinates file.
RDJCL	RDDATA program + Input for program
RTURC15	Input TAPE15 for SSIN/CLASSI
RTURC16	Input TAPE16 for SSIN/CLASSI
RTURC17	Input TAPE17 for SSIN/CLASSI.
RTURBC2	Input for SSIN/CLASSI. EL. 101'
RTURC02	TAPE 2 from SSIN/CLASSI. EL. 101'
RTURBC3	Input for SSIN/CLASSI. EL. 1036'
RTURC03	TAPE 2 from SSIN/CLASSI. EL. 1036'
RTURBCM	Input for SSIN/CLASSI. Center of Mass

REV	BY	DATE	CHECKED	DATE
0	RA	6/8/88	SMD	7/5/88

IMPELL CORPORATION

JOB NO 1390-027-1355

CALC NO TURB-02

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FILE NAME	DESCRIPTION
RTURCOM	TAPE 2 from SSIN/CLASS2 Center of Mass.
RESTURB	Input for RESPEC. Turbine Base
RSTURB	TAPE 9 from RESPEC. Turbine Base
RTURPLB	Input for EDSPLOT. Turbine Base spectra.
NRSTURB	Plot file Turbine Base Spectra.
RTURR02	Response spectra at EL. 1011'. TAPE 9 RESPEC.
TIBI2	Input file for BMENV. EL 1011'
BMENV2	Program BMENV Source.
TISI2	Input for SPECTIA. EL. 1011'
TISO2	Output Tape7 from SPECTIA
TIEI2	Input for EDSPLOT. Broadened spectra at EL 1011'
TIEP2	Plot file. Broadened spectra. EL 1011'.
TIPI2	PVRC Input file. EL 1011'
TPVRC2	JCL file for PVRC. EL 1011'
TIPU2	TAPE2 from PVRC. EL. 1011'
TISI2P	Input for SPECTIA. PVRC Damping. EL 1011'
TISO2P	Output TAPE7 from SPECTIA. PVRC Damping EL 1011'

REV	BY	DATE	CHECKED	DATE
0	RA	6/8/84	CAD	8/1/84

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FILE NAME	DESCRIPTION
TIEI2P	EDSPLOT Input File. PYRC Spectra. EL 1011'
TIEP2P	Plot file. PYRC Spectra. EL 1011'
RTURR03	TAPE9 RESPEC. EL 1036'
TIBI3	Input file for BMENV. EL. 1036'
TISI3	SPECTRA Input file. EL. 1036'
TISO3	Output TAPE7 from SPECTRA. EL. 1036'
TIEI3	EDSPLOT Input Broadened Spectra. EL. 1036'.
TIEP3	Plot file. Broadened Spectra. EL 1036'
TPYRC3	PYRC JCL file. EL. 1036'
TIPI3	PYRC Input file. EL 1036'
TIPO3	TAPE2 from PYRC. EL 1036'
TISI3P	SPECTRA Input. PYRC Damping. EL 1036'
TISO3P	TAPE2 SpectRA. PYRC Damping. EL. 1036'.
TIEI3P	EDSPLOT Input file. PYRC Damping EL. 1036'
TIEP3P	Plot file PYRC Spectra. EL. 1036'

REV	BY	DATE	CHECKED	DATE
0	RA	6/8/88	[illegible]	7/1/88

IMPELL CORPORATION

JOB NO 1390-027-1355

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9.2 SEISMIC ANCHOR MOVEMENT

The following input and output files for the program DISPL are saved on VSN Tape No. 017880.

Input Accn. T.H. File for DISPL	Output Disp. T.H. File from DISPL	Computer Run Log No.	DESCRIPTION
TU2D	TU2DD	TURB-02-25	Turbine + Office El 1011' & Base.
TU3D	TU3DD	TURB-02-27	Turbine + Office El 1036' & Base.
TU4D	TU4DD	TURB-02-29	Turbine + Office El 1051' & Base.
TU5D	TU5DD	TURB-02-31	Turbine + Office El. 1073.5' & Base
TU6D	TU6DD	TURB-02-33	Turbine + Office El 1092.9' & Base
TU23D	TU23DD	TURB-02-35	Turbine + Office. El 1036' & 1011'
TU34D	TU34DD	TURB-02-37	Turbine + Office El 1051' & 1036'
TU45D	TU45DD	TURB-02-39	Turbine + Office El 1073.5' & 1051'
TU56D	TU56DD	TURB-02-41	Turbine + Office. El. 1092.9' & 1073.5'
TU8D	TU8DD	TURB-02-43	Turbine Generator. El. 1031.0' & Base
AT8D	AT8DD	TURB-02-45	Auxiliary Base and Turbine Base

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0	RA	6/8/88	SND	7/5/88

IMPELL CORPORATION

JOB NO 1390-027-1355

CALC NO TURB-02

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10. REFERENCES

(1) Impell calc TURB-01, "Turbine + Office Buildings + Turbine Generator Foundation Structural Models", Client: OPPD, Project: Fort Calhoun, Job No. 1390-027-1355 Rev 0.

(2) Impell calc THG-01, "Time History Generation", Client: OPPD, Project: Fort Calhoun, Job No. 1390-027-1355. Rev 0.

(3) Impell calc. SOIL-01, "Development of Soil properties for SSI Analyses", Client OPPD, Project FortCalhoun, Job No. 1390-027-1355 Rev 0.

(4) Technical Input: (a) Drawing No. 11405-S-291, Base Slab EL 990, Rows 1-3, Rev 7, 1/21/75. (b) Base Slab El. 990, Rows 4-6, Rev. 5, 1/21/75 and (c) Base Slab EL 990, Rows 6-9 Rev. 6 1/21/75.

(5) US NRC Standard Review Plan, Office of Nuclear Reactor Regulation, Report # NUREG-0800.

(6) Impell Standard Program CLASSI, Version 0.0 Dated 6/19/86

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IMPELL CORPORATION

JOB NO 1390-027-1355
CALC NO TURB-02

(7) "RESPEC", Project specific Vax Version of Impell Standard Program Respec Version 3/9/88.

(8) "BMENV", Project Specific Program Version 4/25/88.

(9) "SPECT1A", Impell Standard Program. Version 1/20/78.

(10) "EDSPLOT", Impell Standard Program. Version May 1987.

(11) U.S. NRC Regulatory Guide 1.122, "Development of Floor Design Response Spectra for Seismic Design of Floor Supported Equipment or Components." Feb. 1978

(12) Technical Input, Drawing No. 11405-S-274. Rev. 11 Rev Date 1/17/75. Piling Plan Turbine Room & Service Building.

(13) Project specific program RDDATA. See Impell calc. INT-04, Project Fort Calhoun, Client: OPPD, Rev. 0 Job No. 1390-027-1355 for verification of RDDATA.

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0	PA	6/8/88	SND	7/5/88

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JOB NO 1390-027-1315

CALC NO TURB-02

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(14) Docket No. 50285, Fort Calhoun Updated Safety Analysis Report (USAR), Revision 7/87.
(Appendix F)

(15) "DISPL", Project Specific Program to calculate Displacement Time History From Acceleration Time History. Version June '88

(16) U.S. Atomic Energy Commission, Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants," October 1973

(17) Impell Calc. AUX-05, "Seismic Anchor Movements (SAM) For Auxillary, Internal and Containment Buildings," Rev 0, Client OPPD, Project Fort Calhoun, Job No. 1390-027-1355.

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APPENDIX A

IMPELL CORPORATION

COMPUTER PROGRAM ABSTRACT

PROGRAM NAME: DISPL VERSION: MAY 1988 DATE: 5/88

TECHNICAL RESPONSIBLE PERSON: R. ALLAHABADI REGION: WR

PRINCIPAL USE: Computation of Displacement Time Histories from Acceleration Time Histories

CODE COMPLIANCE:

PROGRAM LANGUAGE: [X] FORTRAN [ ] FORTRAN EXTENDED [ ] COBOL [ ] ALGOL [ ] OTHER ____

PROGRAM CATEGORY: STANDARD [ ]

PROJECT SPECIFIC [X]

PUBLIC DOMAIN [ ]

HARDWARE CYBER 990

OPERATING SYSTEM NOS 2.5

PROGRAM HAS BEEN: [X] VERIFIED [ ] CODE CERTIFIED

APPLICABLE USER'S MANUAL INSTRUCTIONS: VERSION: MAY 1988

DATE: 5/88

REVISION: MAY 1988

DESCRIPTION OF PROGRAM:

See attached sheets

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO 1890-027-1355	
CALC/PROB NO TURB-02	
BY RA	DATE 7/5/88
CHKD SAD	DATE 7/5/88

APPENDIX A

VERIFICATION OF PROGRAM DISPL

A.1 INTRODUCTION

Program DISPL double integrates acceleration time histories to calculate displacement time histories. Double integration is carried out in frequency domain. The Logic of program DISPL is as follows:

(1) Calculate Fourier spectra for acceleration time history.

(2) Calculate displacement Fourier spectra from acceleration Fourier spectra use the following relationship.

$$S_{df} = -\frac{1}{\omega^2} S_{da}$$

where

S_{df} = Displacement Fourier spectral value at frequency ω.

ω = Frequency in radians/sec

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IMPELL CORPORATION

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CALC NO TURB-02

S_{d_a} = Acceleration Fourier spectral value at frequency ω.

(3) Use inverse Fourier transform to calculate displacement time history from displacement Fourier spectra

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A.2 DISPL PROGRAM FEATURES

The DISPL program has the following features:

(1) It can double integrate one acceleration time history, or relative acceleration time history. For integration of relative acceleration time history, user inputs two acceleration time histories. Program automatically subtracts the second acceleration time history from the first.

(2) It can automatically generate sine or cosine wave time histories. Only one wave can be generated in the form of a time history. The phase angle for the generated sine or cosine wave time histories is always zero.

A.3 PROGRAM VERSION

The version of the program is May 1988. The compiled listing of the source is given in CBL # TURB-02-46.

The User's Guide is included in the source code (at the beginning of the code). A copy of the User's Guide is contained in the next two pages.

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IMPELL CORPORATION

JOB NO 1390-027-1355

CALC NO TURB-02

```
      PROGRAM DISPL(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7,TAPE1)
C
C*****************************************************************
C
C     USERS GUIDE
C  ***************************************************************
C
C     READ FROM INPUT THE FOLLOWING DATA
C
C  ***************************************************************
C
C     0. PROBLEM DEFINITION (I5)
C
C        1- 5     NCASE        TOTAL NUMBER OF CASES TO BE ANALYZED
C                              ** NOTE **
C                              REPEAT STEP 2 TO 5 NCASE TIMES
C                              DEFAULT NCASE=1
C
C     1. RUN TITLE CARD (12A6)
C
C        1-72     TITLE()      ANY CHARACTERS FOR RUN ID.
C
C     2. GENERAL INFORMATION CARD (2I5,F10.0,2I5)
C
C        1- 5     NOPT         TOTAL NO. OF EQ RECORDS
C                              SHOULD BE 1 OR 2
C                              DEFAULT IS 2
C        6-10     N3           TOTAL NO. OF DIGITIZED POINTS IN EQ MOTION
C       11-20     DT           TIME INTERVAL OF DIGITIZED MOTION IN SEC.
C       21-25     KGMAX        TOTAL NO. OF POINTS USED FOR FAST FOURIER
C                              TRANSFORMATION
C                              MUST BE POWER OF 2 (1024,2048,ETC)
C       26-30     NHEAD        TOTAL NO. OF HEADER CARDS BEFORE THE DIGITIZED
C                              MOTION
C       36-40     KHEAD        TOTAL NUMBER OF HEADER CARDS OF SECOND
C                              MOTION
C
C     3. CONTROL CARD OF EARTHQUAKE MOTION (F10.0,A6,4X,3A6)
C
C        1-10     EQMUL        EARTHQUAKE MULTIFICATION FACTOR
C       11-16     AKEY         IF SINE, PROGRAM GENERATES SINE WAVE
C                              IF COSINE, PROGRAM GENERATES COSINE WAVE
C                              LEAVE IT BLANK, IF MOTION IS READ BY CARDS
C       21-38     IFMT()       IF EQ MOTION IS NOT READ UNDER FORMAT(8F9.6),
C                              SPECIFY USER'S FORMAT SUCH AS (5F15.3) ETC
C
C     4. EARTHQUAKE TITLE CARDS (12A6)
C
C        1-72     EQN()         ANY CHARACTERS FOR MOTION ID PURPOSE
C                               ** NOTE **
C                               REPEAT NHEAD OR KHEAD TIMES
C
C     ** NOTE **
C
C     IF RELATIVE DISPLACEMENTS ARE GOING TO BE COMPUTED,
C     REPEAT STEPS 3-4 FOR THE SECOND EARTHQUAKE MOTION.
C
```

DESIGN VERIFICATION
CLIENT OPPD
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CHKD: SAND   DATE 2/1/88

```
C  ****************************************************************
C
C     READ FROM TAPE7 THE FOLLOWING DATA
C
C  ****************************************************************
C     5. EARTHQUAKE DIGITIZED MOTION (8F9.6)-DEFAULT OR IFMT
C
C        1-9       A(1)        FIRST ACC VALUE OF MOTION
C       10-18      A(2)        SECOND
C         -          .          .
C         -          .          .
C
C     **** NOTE ***
C          IF RELATIVE DISPLACEMENTS ARE GOING TO BE COMPUTED, REPEAT
C          STEP 5 FOR SECOND EARTHQUAKE MOTION
C
C*********************************************************************
C
C
C
      DIMENSION TITLE(12),EQN(12),A(9000),B(9000),INV(2000),S(2000)
C
      CALL IDENT
C
      READ (5,1001) NCASE
      IF(NCASE.EQ.0) NCASE=1
      READ (5,1000) TITLE
      WRITE (6,2000) TITLE
      NOPT=0
      N3=0
      DT=0.0
      KGMAX=0
      NHEAD=0
 1000 FORMAT(12A6)
 2000 FORMAT(1H,/,/,5X,12A6)
C
      REWIND 7
      DO 9999 IJKL=1,NCASE
      READ (5,1001) KNOPT,KN3,DDT,KKGMAX,NNHEAD,KHEAD
C
      IF(KNOPT.NE.0) NOPT=KNOPT
      IF(KN3.NE.0) N3=KN3
      IF(DDT.GT.0.0) DT=DDT
      IF(KKGMAX.NE.0) KGMAX=KKGMAX
C
      WRITE (6,2001) NOPT,N3,KGMAX,NHEAD,KHEAD,DT
 1001 FORMAT(2I5,F10.0,3I5)
 2001 FORMAT(///,5X,7HNOPT = ,I5,/,5X7HN3    = ,I5,/,5X,7HKGMAX= ,I5,/,
     1          5X,7HNHEAD= ,2I5,/,5X,7HDT    = ,F10.5,7H  SEC.      )
C
      IF(NOPT.NE.1) NOPT=2
C
C     SET UP ALL CONSTANTS FOR OPERATION
C
      N=2
      M1=1
  100 M1=M1+1
```

DESIGN VERIFICATION

CLIENT OPPD	
JOB NO 1390-023-1355	
CALC/PROB NO TURB-02	
BY BS	DATE 7/5/88
CHKD CAD	DATE 7/5/88

7/88

A.4 VERIFICATION EXAMPLE

In one run, three time histories are double integrated. These time histories are as follows:

(1) $\sin \frac{2\pi}{40.96} t$

(2) $\cos \frac{2\pi}{40.96} t$

(3) $3 \sin \frac{2\pi}{40.96} t - 2 \sin \frac{2\pi}{40.96} t$

All three time histories have only one full wave, and amplitude of wave = 1.0

Displacement time histories corresponding to above acceleration time histories are

(1) $-\left(\frac{40.96}{2\pi}\right)^2 \sin \frac{2\pi}{40.96} t$

(2) $-\left(\frac{40.96}{2\pi}\right)^2 \cos \frac{2\pi}{40.96} t$

(3) $-\left(\frac{40.96}{2\pi}\right)^2 \sin \frac{2\pi}{40.96} t$

Maximum displacement value for all the three time histories is

$|\text{Maximum displacement}| = 42.497$

Time for maximum displacement is as

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IMPELL CORPORATION

JOB NO 1390-077-1353

CALC NO TURB-02

follows

(1) -42.497 at 10.24 sec
& 42.497 at 30.72 sec

(2) -42.497 at 0 sec and 40.96 sec
& 42.497 at 20.48 sec

(3) -42.497 at 10.24 sec
& 42.497 at 30.72 sec

By inspection, all three displacement time histories are found to be correctly calculated (Refer to CRSL # TURB-02-07).

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CALC NO TURB-02
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COMPUTER PROGRAM RUN LOG
(OPTIONAL)

CLIENT OPPD PROJECT FORT CALHOUN JOB NUMBER(S) 1390-027-1355

PROGRAM

DESIGN VERIFICATION
CLIENT OPPD
JOB NO. 1390-027-1355
CALC/PROB NO. TURB-02
BY: RA DATE 7/15/88
CHKD: SLD DATE 7/5/88

VERSION	RUN NO	DATE	PROJECT TASK	BY
CLASSI/GLAYER	TURB-02-01	4/29/88	Calc. Foundation Scattering Matrices	RA
CLASSI/CLAF	TURB-02-02	4/29/88	Calc. Foundation Impedances	RA
EDSGAP	TURB-02-03	5/18/88	Calc Fixed Base Mode Shapes & Freq	RA
RDDATA	TURB-02-04	5/18/88	Reformat mode shapes & Freq.	RA
CLASSI/SSIN	TURB-02-05	5/18/88	Calc. Accn. T.H at El 1011'	RA
CLASSI/SSIN	TURB-02-06	5/18/88	Calc Accn. T.H. at El 1036'	RA
CLASSI/SSIN	TURB-02-07	5/26/88	Calc. Accn. T.H. at Centr of Mass	RA
RESPEC	TURB-02-08	5/18/88	Calc Response Spectra at Base	RA
EDSPLOT	TURB-02-09	5/18/88	Plot Response spectra at Base	RA
RESPEC	TURB-02-10	5/27/88	Calc Response spectra El. 1011'	RA
BMENV	TURB-02-11	5/27/88	Envelope Response Spectra. El. 1011'	RA
SPECTIA	TURB-02-12	5/27/88	Broaden " " "	RA
EDSPLOT	TURB-02-13	5/27/88	Plot broadened " " "	RA
PVRC	TURB-02-14	5/27/88	Calc. PVRC Spectra El. 1011'	RA
SPECTIA	TURB-02-15	5/27/88	Broaden PVRC " . El. 1011'	RA
EDSPLOT	TURB-02-16	5/27/88	Plot broadened PVRC " "	RA

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COMPUTER PROGRAM RUN LOG
(OPTIONAL)

CLIENT OPPD PROJECT FORT CALHOUN JOB NUMBER(S) 1390-027-1355

PROGRAM ____________

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1355	
CALC/PP/# NO. TURB-02	
BY: RA	DATE 7/5/8
CHKD SAD	DATE 7/1/88

VERSION	RUN NO	DATE	PROJECT TASK	BY
RESPEC	TURB-02-17	5/26/88	Calc. Response Spectra. EL. 1036'	RA
BMENV	TURB-02-18	5/18/88	Envelope " " EL. 1036'	RA
SPECTIA	TURB-02-19	5/18/88	Broaden " " EL. 1036'	RA
EDSPLOT	TURB-02-20	5/18/88	Plot Broadened " " EL. 1036'	RA
PVRC	TURB-02-21	5/27/88	Calc. PVRC Spectra. EL 1036'	RA
SPECTIA	TURB-02-22	5/27/88	Broaden " " "	RA
EDSPLOT	TURB-02-23	5/27/88	Plot broadened PVRC " "	RA
REF02	TURB-02-24	5/26/88	Reformat Accn. T.H. 1011' & Base	RA
DISPL	TURB-02-25	5/26/88	Calc. Rel. Disp. T.H. 1011' - Base	RA
REF02	TURB-02-26	5/26/88	Reformat Accn. T.H. 1036' & Base	RA
DISPL	TURB-02-27	5/26/88	Calc. Rel. Disp T.H. 1036' - Base	RA
REF02	TURB-02-28	5/26/88	Reformat Accn. T.H. 1051' & Base	RA
DISPL	TURB-02-29	5/26/88	Calc Rel Displ. T.H. 1051' - Base	RA
REF02	TURB-02-30	5/26/88	Reformat Accn. T.H. 1073.5' & Base	RA
DISPL	TURB-02-31	5/26/88	Calc. Rel Displ. T.H. 1073.5' - Base	RA
REF02	TURB-02-32	5/26/88	Reformat Accn. T.H. 1092.0' & Base	RA

COMPUTER PROGRAM RUN LOG
(OPTIONAL)

IMPELL

CLIENT OPPD PROJECT FORT CALHOUN JOB NUMBER(S) 1390-027-1355

PROGRAM

DESIGN VERIFICATION
CLIENT OPPD
JOB NO. 1390-027-1355
CALC/PROB NO. TURB-02
BY RA DATE 7/5/88
CHKD SAD DATE 7/1/88

VERSION	RUN NO	DATE	PROJECT TASK	BY
DISPL	TURB-02-33	5/26/88	Calc. Rel. Displ. T.H. 1092.0' - Base	RA
REF04	TURB-02-34	6/7/88	Reformat Accn. T.H. 1036' & 1011'	RA
DISPL	TURB-02-35	6/7/88	Calc. Rel. Disp. T.H. 1036' - 1011'	RA
REF04	TURB-02-36	6/7/88	Reformat Accn. T.H. 1051' & 1036'	RA
DISPL	TURB-02-37	6/7/88	Calc. Rel. Disp. T.H. 1051' - 1036'	RA
REF04	TURB-02-38	6/7/88	Reformat Accn. T.H. 1073.5' & 1051'	RA
DISPL	TURB-02-39	6/7/88	Calc. Rel. Disp. T.H. 1073.5' - 1051'	RA
REF04	TURB-02-40	6/7/88	Reformat Accn. T.H. 1092.0' & 1073.5'	RA
DISPL	TURB-02-41	6/7/88	Calc. Rel. Displ. T.H. 1092.0' - 1073.5'	RA
REF02	TURB-02-42	5/27/88	Reformat Accn. T.H. T.Gen. 1036' & Base	RA
DISPL	TURB-02-43	5/27/88	Calc. Rel. Disp. T.H. T.Gen 1036' - Base	RA
REF02	TURB-02-44	5/27/88	Reformat Turb. and Aux. Base T.H.	RA
DISPL	TURB-02-45	5/27/88	Calc. Rel. Displ. T.H. between Turb & Aux. Base	RA
DISPL	TURB-02-46	5/23/88	Compiled DISPL listing.	RA
—	—		—	—
DISPL	TURB-02-47	6/3/88	Verification Example of DISPL	RA

ATTACHMENT A

ATTACHMENT A SHT A1 OF A4
IMPELL CALCULATION NO. TURB-02

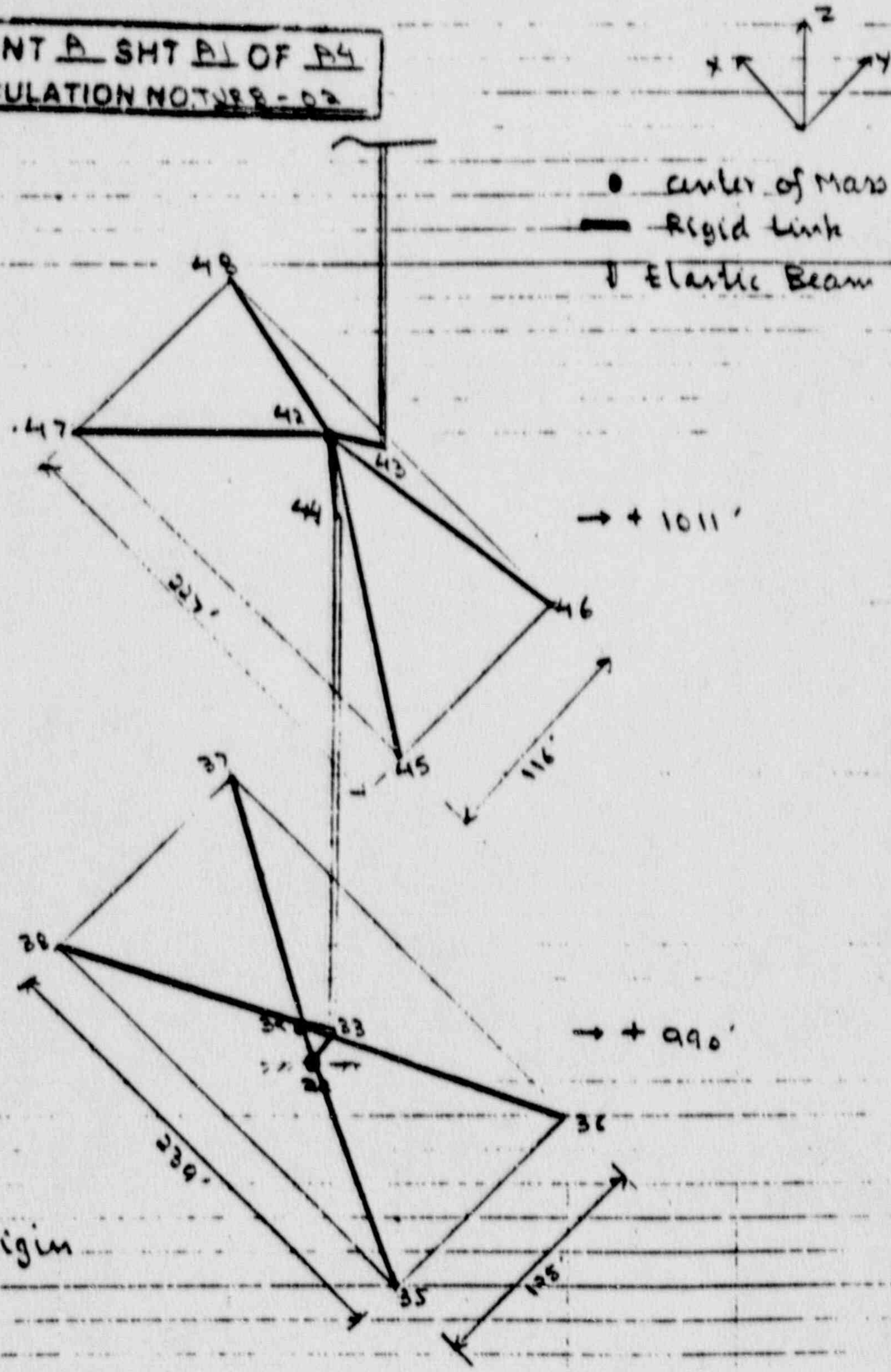

FIG. 2.1(a) TURBINE + OFFICE BUILDING MODEL

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ATTACHMENT A SHT B2 OF B4
IMPELL CALCULATION NO. TURB-01

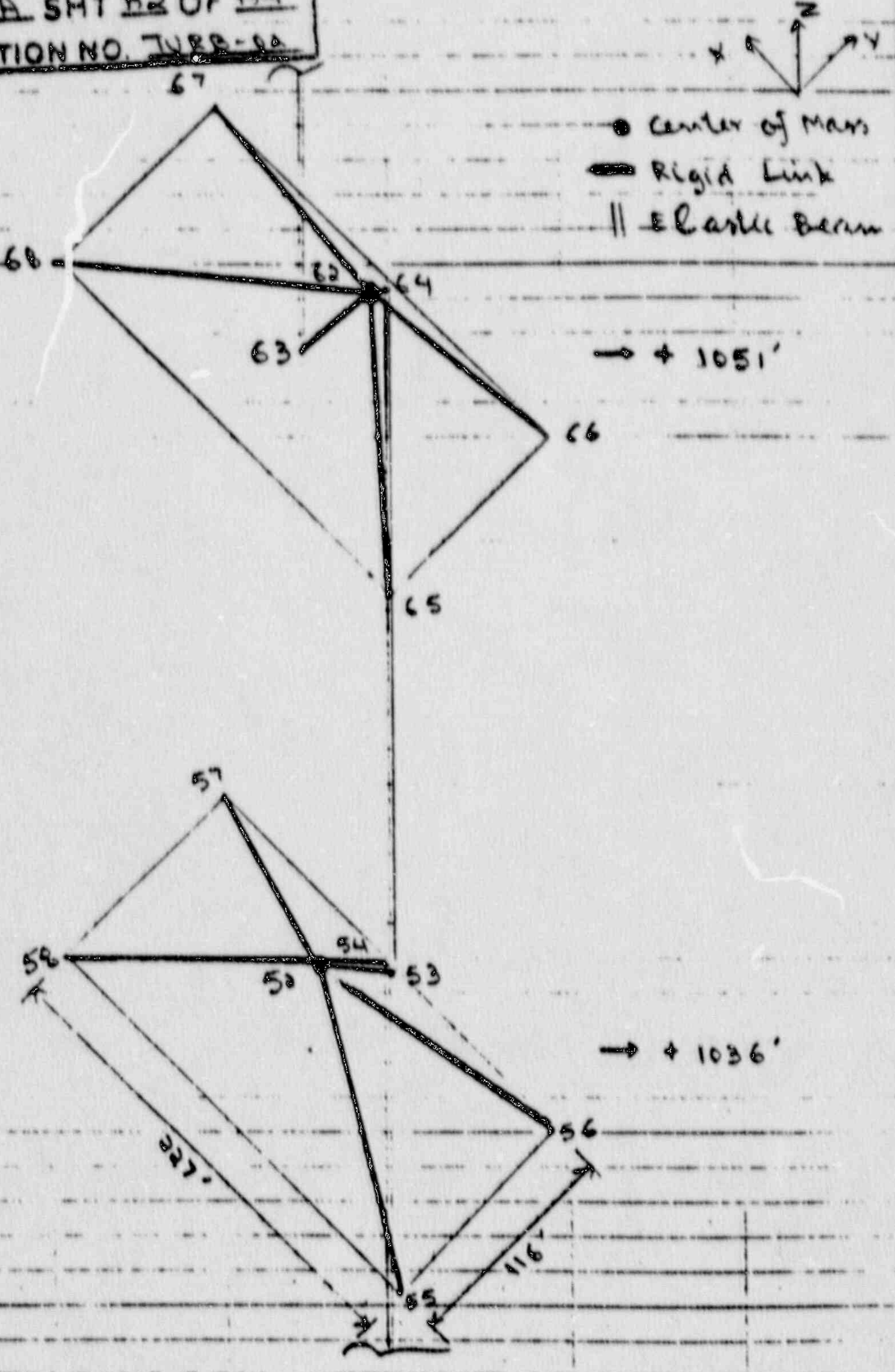

FIG 2.1(a) TURBINE + OFFICE BUILDING MODEL (CONT'D.)

0	RA	4/27/88	SAD	5/14/88	IMPELL CORPORATION	JOB NO 1390-037-1355 CALC NO TURB-01	PAGE 12 OF
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ATTACHMENT B SHT B2 OF B4
IMPELL CALCULATION NO. TURB-02

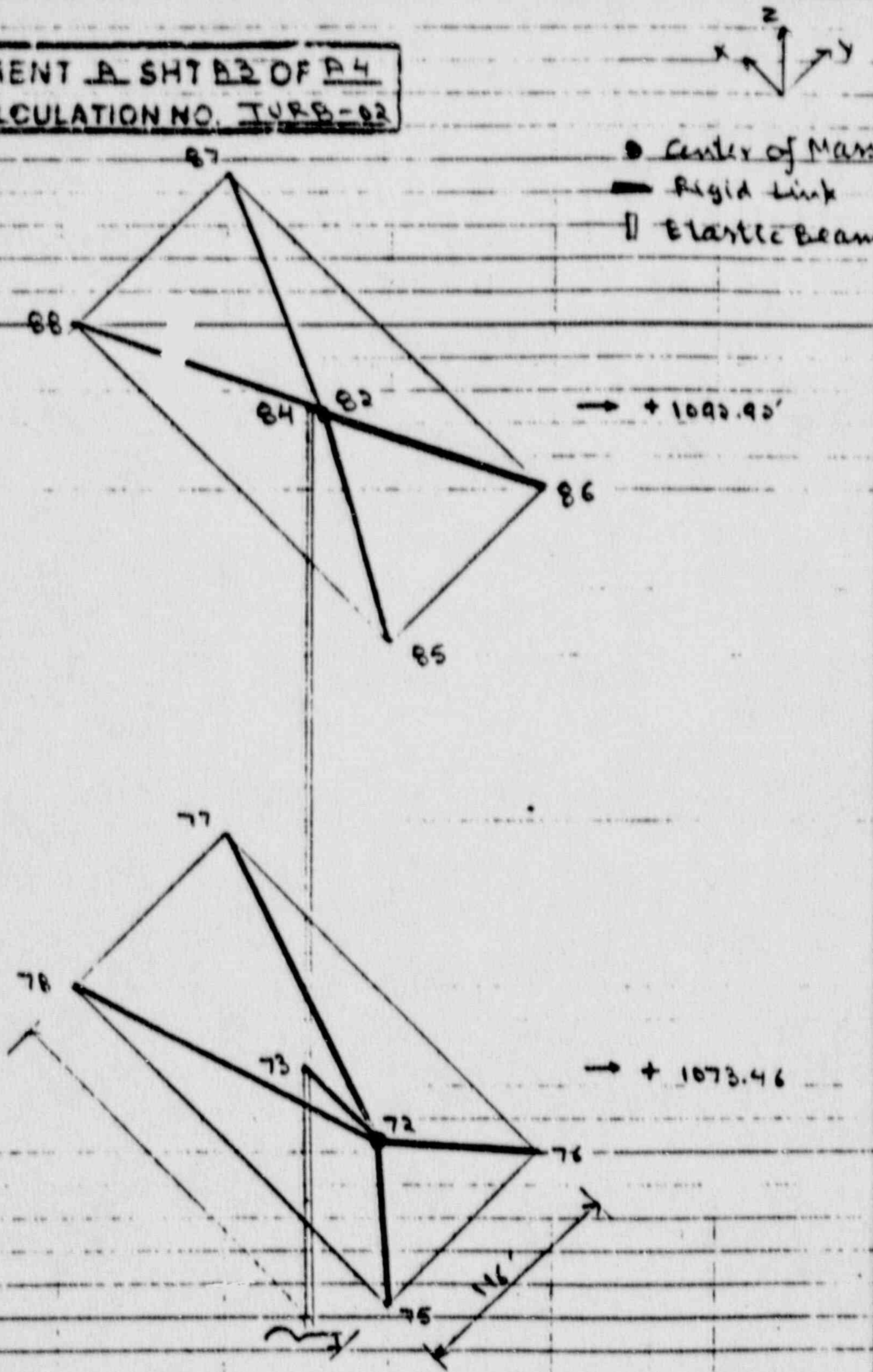

FIG. 2.1 (a) TURBINE + OFFICE BUILDING MODEL (CONTD.)

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ATTACHMENT B SHT B4 OF B4
IMPELL CALCULATION NO. TURB-02

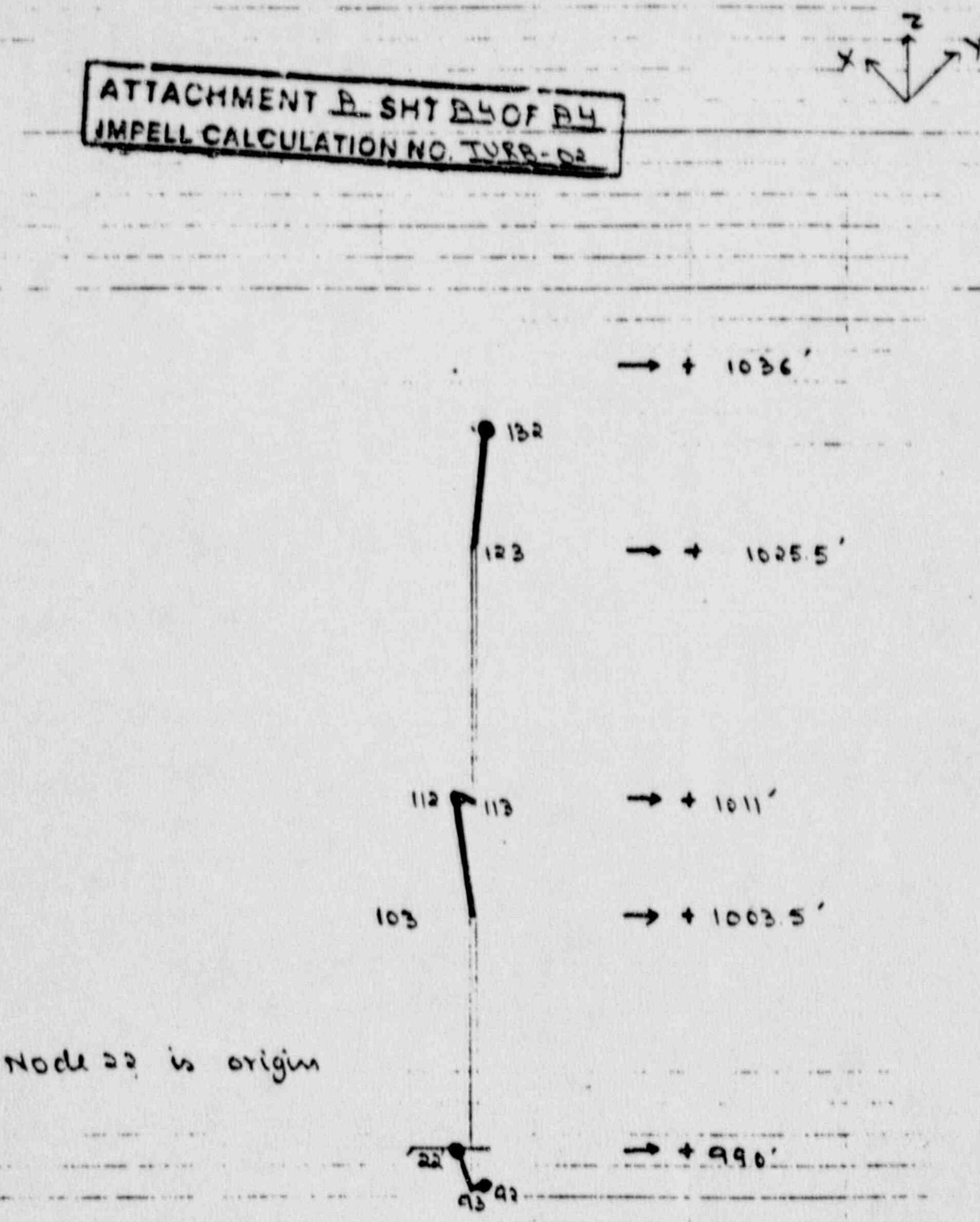

FIG. 2.1 (b) TURBINE GENERATOR FOUNDATION MODEL

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ATTACHMENT 4
IMPELL CALCULATION No. RAN-01, REV. 0

CALCULATION/PROBLEM COVER SHEET

Calculation/Problem No: RAN-01

Title: VERIFICATION OF PROJECT SPECIFIC PROGRAM RANDUM

Client: OPPD **Project:** FORT CALHOUN

Job No: 1390-027-1355

Design Input/References:

Stated within.

Assumptions:

Stated within

Method:

Stated within

Remarks:

This calc. also contains pages i, ii and 5a.

REV. NO.	REVISION	APPROVED	DATE
0	Original	[signature]	9/26/88
1	Incorporated QA's comments @ pg. 5a, 49, 8	[signature]	2/6/89
	MICROFILMED	[signature] for RAB 2-7-89 Q A Concurrence Date	

EDS 0000 8/0

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3. THEORY	4
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4.3 VERSION 3	12
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1 INTRODUCTION

It is often necessary to generate floor acceleration response spectra from design ground acceleration response spectra. A common procedure of doing so, known as the time history approach, requires (1) generating artificial time histories that envelope the design ground acceleration response spectra, and (2) using the artificial time histories as input for soil-structure interaction (SSI) analysis to generate floor acceleration spectra.

Time history procedure is conservative since the artificial time histories, in general, have excess energy than specified by the design spectra. An alternative approach is to use random vibration theory. In the random vibration theory approach, power spectral density function (PSDF) is generated which match the

design ground spectra. This input PSDF is transformed to PSDF at a floor (output) using transfer function obtained from SSI analysis. Then the output PSDF is converted to floor (output) response spectra.

An independent SASSI module called "RANDOM" is developed, which uses the random vibration theory approach to generate floor response spectra from design ground spectra.

2. PURPOSE

The purpose of this calc. is to verify module RANDOM as an independent project specific program for the OPPD (client) Fort Calhoun project. This program will be used to calculate floor response spectra for OBE event only. the program options that will be used in Fort Calhoun project are verified.

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JOB NO 1370-027-1355

CALC NO RAN-01

3. THEORY

Random module is based on random vibration theory. Logic of the module is as follows:

(1) Generate a power spectral density function that matches the given input design spectra. This requires iteration process. The theory and the details of the iteration process are discussed in reference [1]. Therefore, they are not repeated here.

(2) Transfer the input power spectral density to output power spectral density function. Output power spectral density function is given by [2]

$$P(f)_o = TF(f)^2 * P(f)_i$$

where

$P(f)_o$ = Output power spectral density function value at frequency f

$TF(f)$ = Transfer function for frequency (f)

P(f)$_i$ = Input power spectral density function value at frequency (f)

(3) Generate output response spectra for desired damping from the output power spectral density function. Theory and details for this step are also discussed in reference [1], and hence are not repeated here.

The theory and methodology for RANDOM module is identical to the program SPECGEN. The only difference is that it uses transfer functions calculated by SASSI as input to get the output power spectral density function (Step 2).

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COMPUTER PROGRAM ABSTRACT

PROGRAM NAME: RANDOM VERSION: ______ DATE: 6, 1988

TECHNICAL RESPONSIBLE PERSON: Stavro Dermitzakis REGION: WR

PRINCIPAL USE: Direct Generation of Response Spectra

CODE COMPLIANCE:

PROGRAM LANGUAGE: [x] FORTRAN [ ] FORTRAN EXTENDED [ ] COBOL
[ ] ALGOL [ ] OTHER ______

PROGRAM CATEGORY: STANDARD [ ]
PROJECT SPECIFIC [x]
PUBLIC DOMAIN [ ]

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1355	
CALC/PROB NO. RAN-01, Rev. 1	
BY: RA	DATE: 2/6/89
CHKD: MMZ	DATE: 2/6/89

HARDWARE: VAX

OPERATING SYSTEM: VMS

PROGRAM HAS BEEN: [x] VERIFIED [ ] CODE CERTIFIED

APPLICABLE USER'S MANUAL INSTRUCTIONS: VERSION: 3.0
DATE: 7, 10, 88
REVISION: ______

DESCRIPTION OF PROGRAM:

Generates output response spectra from input response spectra and Transfer Functions.

4. VERIFICATION TEST PLAN

Three different versions of the program Random are used for verification purposes. Test plan for the three versions and the difference between them is as follows.

4.1. VERSION 1

Version 1 is a basic version, which is used to test the program theory, and to verify the technical part of the coding. This version allows input spectra in one direction, and generates output spectra at various damping at one location only.

Two test problems will be performed to verify version 1.

Test Problem 1

Input: Ground acceleration response spectra generated from the artificial time history in N-S dir. used in Impell calc AUX-03 [3].

Output : Floor acceleration response spectra at center of mass, elev. 1044' of Aux Building, in N-S direction.

The output will be compared against the floor spectra generated using the time history approach to verify the theory.

Test Problem 2

Input : Design ground acceleration response spectra for SSE event at Fort Calhoun in N-S direction

Output : Floor acceleration response spectra at center of mass, elev. 1044' of Aux. Building, in N-S direction.

The output will be compared against the floor spectra generated using the time history approach to show the benifits of random theory approach.

4.2 VERSION 2

This version allows input spectra in three directions simultaneously. Output spectra at a location in one direction is SRSS of response due to various input spectra. It also allows response spectra to be calculated at more than one location in one run. Several print options are added that allows the user to control the output volume.

Five test problems will be performed to verify version 2. ⚠1

Test Problem 1

Input = Design ground acceleration response spectra for SSE event at Fort Calhoun in N-S Direction

Output = Floor response spectra at center of mass, elev. 1044' of Aux. Building in N-S direction

Output will be compared with Test problem 2. This is to avoid rerunning test problems

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0	RA	6/22/88	WJT	7/6/88		CALC NO RAN-01

for version 1

Test Problem 2

Same as test problem 1. However, output response spectra will be for Y (E-W) direction.

Test Problem 3

Same as test problem 1. However, output response spectra will be for Z (Vert) direction.

Test Problem 4

If two response spectra are related to each other by a scale factor, f, the corresponding PSDF are related by factor, f^2. That is

If

$$RS_1 = f \times RS_2$$

then

$$PSDF_1 = f^2 \times PSDF_2$$

where

RS = Response Spectra

PSDF = Power Spectral Density Function

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Thus, if input response spectra in one direction is related to input response spectra in another direction, user need to input only the scale factor f.

Test problem 4 verifies the above relationship.

Input = Design ground acceleration response spectra for SSE event at Fort Calhoon in N-S direction, scaled by a factor of 0.6667

Output = Same as test problem 1.

PSDF and output response spectra of this problem will be compared against results from test problem 1 to verify the relationship.

Test Problem 5

Version 2 allows the output spectra to be calculated at more than one location due to simultaneous input in three directions. SRSS combination rule is used to calculate output spectra

If input spectra is same, user need to specify input spectra, once only.

Test problem 5 verifies the above options.

Input = Design horizontal ground spectra for SSE event at Fort Calhoun in N-S, and E-W direction. For vertical direction, horizontal spectra is scaled by a factor of 0.6667.

Output = Response spectra at center of mass, elev 1044' of Aux Building in N-S direction.

Output spectra will be calculated twice at the same location, to verify the option to calculate output spectra at more than one location.

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JOB NO 1390-027-1355

CALC NO RAN-01

4.3 VERSION 3

This version has same features as version 2. In addition, it allows the user to stop after calculating PSDF for input spectra (i.e performs only step 1 of Section 3.)

Two test problems are used to verify this version.

Test Problem 1:

This test problem is same as Test problem 5 in Section 4.2. This will verify version 3 with respect to version 2.

Test Problem 2:

INPUT: Design spectra for SSE event at Fort Calhoun.

OUTPUT: PSDF for input spectra. PSDF are also saved on Tape7. PSDF will be compared against test problems for version 2.

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JOB NO 1390-027-1355

CALC NO RAN-01

5. TEST PROBLEMS AND RESULTS

Impell standard program CLASSI [4] is used to calculate response acceleration time histories, using the time history approach, and also the transfer functions (see Impell calc. INT-05 [5] for verification of transfer function option). Impell Standard program RESPEC [6] or project specific version of Impell standard program RESPEC[7] is used to calculate acceleration spectra. Impell standard program EDSPLOT [8] is used for plotting.

5.1 VERSION 1 (SSG.FOR)

Response spectra for input time histories in X, Y, and Z direction is calculated in CRL# RAN-01-01, for 2, 3, 4, 5, 7, 10 and 15% damping. Response spectra at [illegible] of mass elevation 1044' in X direction for 1% damping is calculated in CRL# RAN-01-02, and for 2, 3, 4, 5, 7, 10 & 15%

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in CRL # RAN-01-03.

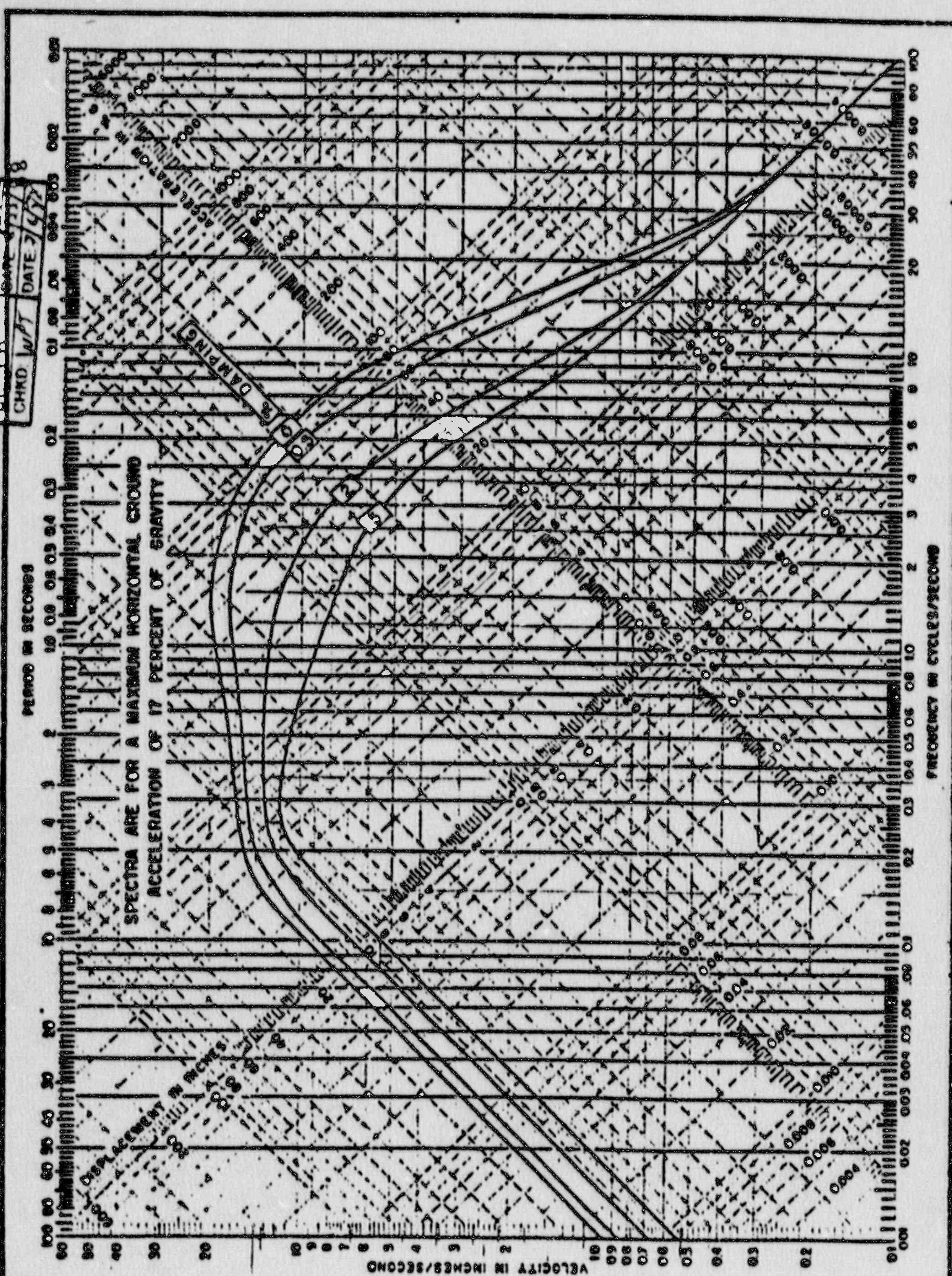
Source listing for version 1 is contained in CRL# RAN-01-04.

Horizontal design spectra for SSE event at Fort Calhoun - Unit No. 1 is shown in Fig. F2. Digitized values for design spectra at 2% and 5% are as follows.

DIGITIZED HORIZONTAL DESIGN SPECTRA

FREQ (HZ)	ζ = 2% in/sec²	ζ = 5% in/sec²
0.3	2.07	-
0.33	-	2.09
0.50	3.48	2.90
0.80	5.45	3.86
1.0	6.70	4.51
1.2	7.85	5.09
1.5	9.27	5.96
2.0	10.89	7.15
2.5	12.04	8.05
3.0	13.04	8.05
4.0	12.57	8.18
5.0	11.78	7.89
6.0	10.84	7.15
7.0	9.53	6.63
8.0	9.01	6.12
9.0	8.25	5.06
10.0	7.70	5.76
12.0	7.54	5.64
15.0	6.28	5.47
20.0	5.55	5.47
25.0	5.63	5.47
34.0	5.70	5.47
40.0	5.70	5.47

DESIGN VERIFICATION
CLIENT
JOB NO
CALC/PROB NO
BY
CHKD
DATE



OMAHA PUBLIC POWER DISTRICT FORT CALHOUN STATION - UNIT NO. 1

RESPONSE SPECTRA
MAXIMUM HYPOTHETICAL EARTHQUAKE

FIG. F-2

For each of the two test problems, three runs are made:

(1) Generate 2% and 5% output spectra from 2% and 5% input spectra, respectively.

(2) Generate 3% and 4% output spectra from the average PSDF of 2% and 5% input spectra.

(3) Generate 7%, 10% and 15% output spectra from 5% input spectra.

An additional run is made for test problem 1 to generate 1% output spectra from 2% input spectra.

Fig. 5.1 through 5.8 show the results for test problem 1. From these figures, it is concluded that version 1 is verified.

Fig 5.9 through 5.15 show the results for test problem 2. These figures clearly show the reduction in output spectra for random theory approach

over the time history approach.

CRL # associated with test problem are as follows

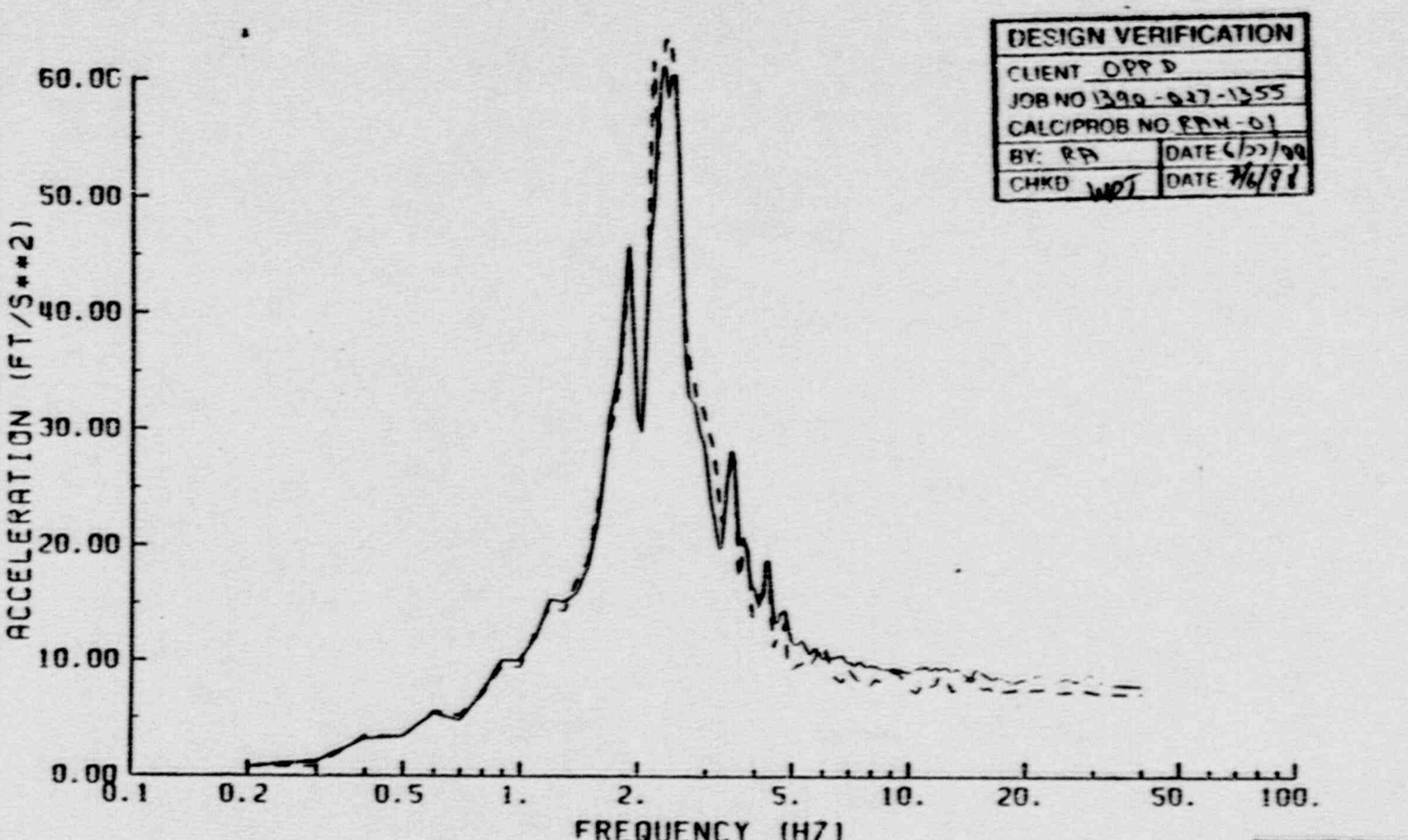
S.No.	Description	CRL #
(1)	Test Problem 1, Run 1	RAN-01-05
(2)	Test Problem 1, Run 2	RAN-01-06
(3)	Test Problem 1, Run 3	RAN-01-07
(4)	EDSPLOT for (1)	RAN-01-08
(5)	EDSPLOT for (2)	RAN-01-09
(6)	EDSPLOT for (3)	RAN-01-10
(7)	Test Problem 2, Run 1	RAN-01-11
(8)	Test Problem 2, Run 2	RAN-01-12
(9)	Test Problem 2, Run 3	RAN-01-13
(10)	EDSPLOT for (7)	RAN-01-14
(11)	EDSPLOT for (8)	RAN-01-15
(12)	EDSPLOT for (9)	RAN-01-16
(13)	Test Problem Run 4	RAN-01-17
(14)	EDSPLOT for (13)	RAN-01-18

REV	BY	DATE	CHECKED	DATE
0	RA	6/22/86	WPT	7/6/88

IMPELL CORPORATION

JOB NO 1340-027-1355
CALC NO RAN-01

FIG. 5.1



SSG.FOR VERIFICATION/ PROBLEM 1, RUN 1A
OPPD, AUX. BLDG., ELEV. 1044, C.G., N-S DIRECTION
DAMP.= 1 PERCENT SOLID= SSG.FOR DASH= RESPEC

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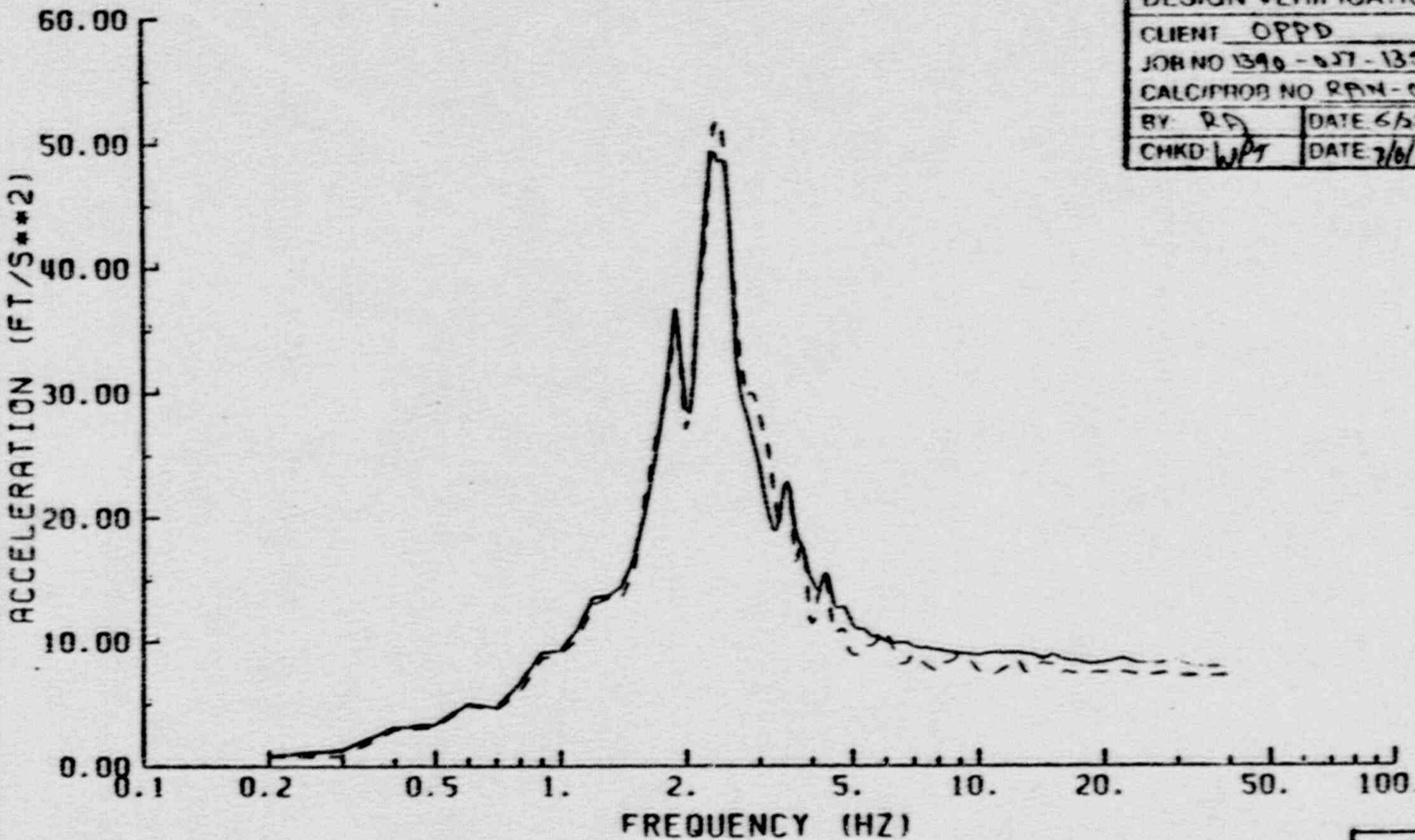
FIG. 52

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO 1390-027-1355	
CALC/PROB NO RPM-01	
BY: RP	DATE 6/22/88
CHKD: WPT	DATE 7/6/88



SSC.FOR VERIFICATION/ PROBLEM 1, RUN 1
OPPD, AUX. BLDG., ELEV. 1044, C.G., N-S DIRECTION
DAMP.= 2 PERCENT SOLID= SSC.FOR DASH= RESPEC

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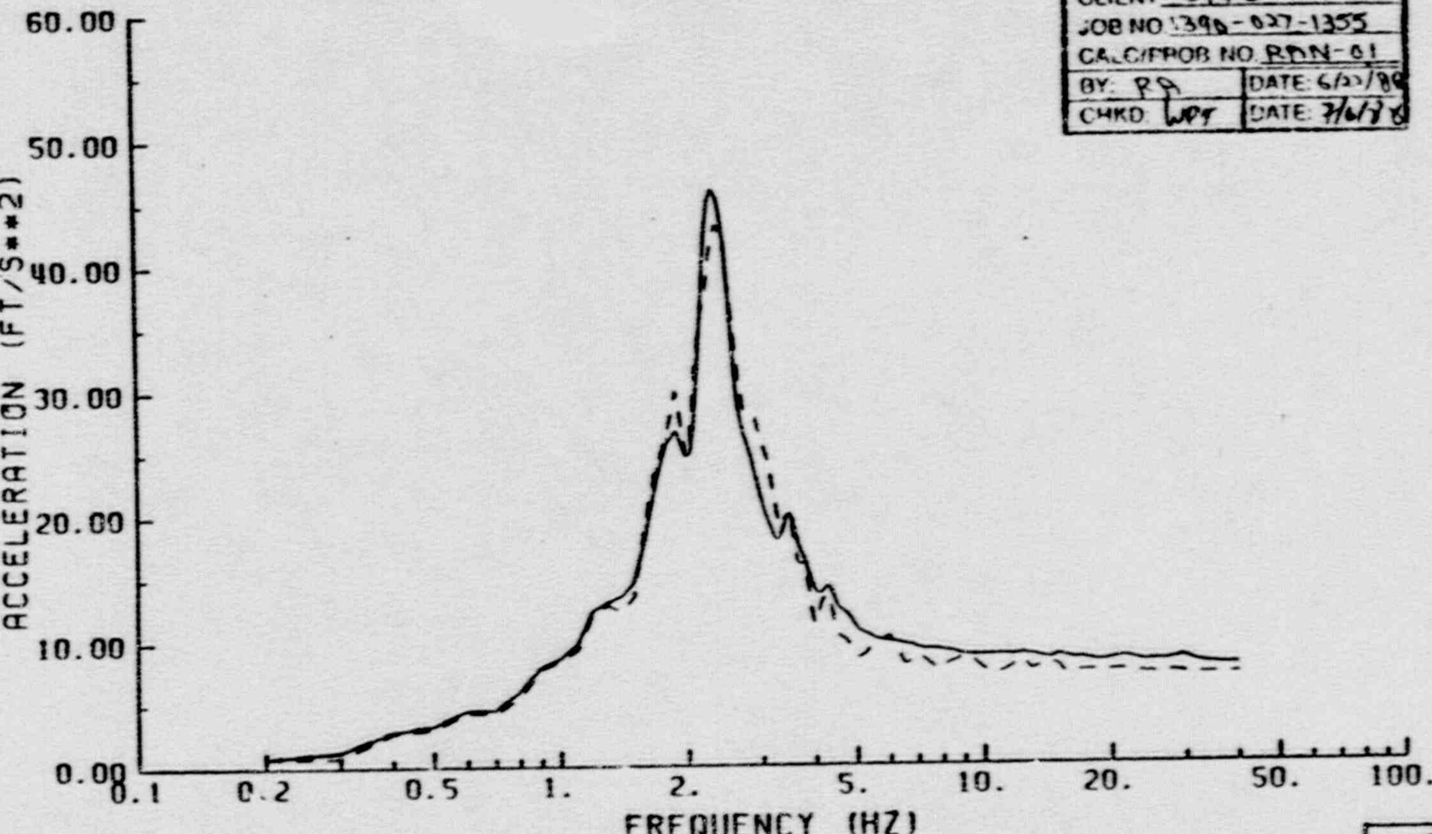
FIG. 5.3

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO 1390-027-1355	
CALC/PROB NO. RDN-01	
BY: RA	DATE: 6/23/88
CHKD: WPT	DATE: 7/6/88



SSC.FOR VERIFICATION/ PROBLEM 1, RUN 3
OPPD, AUX. BLDG., ELEV. 1044, C.G., N-S DIRECTION
DAMP.= 3 PERCENT SOLID= SSC.FOR DASH= RESPEC

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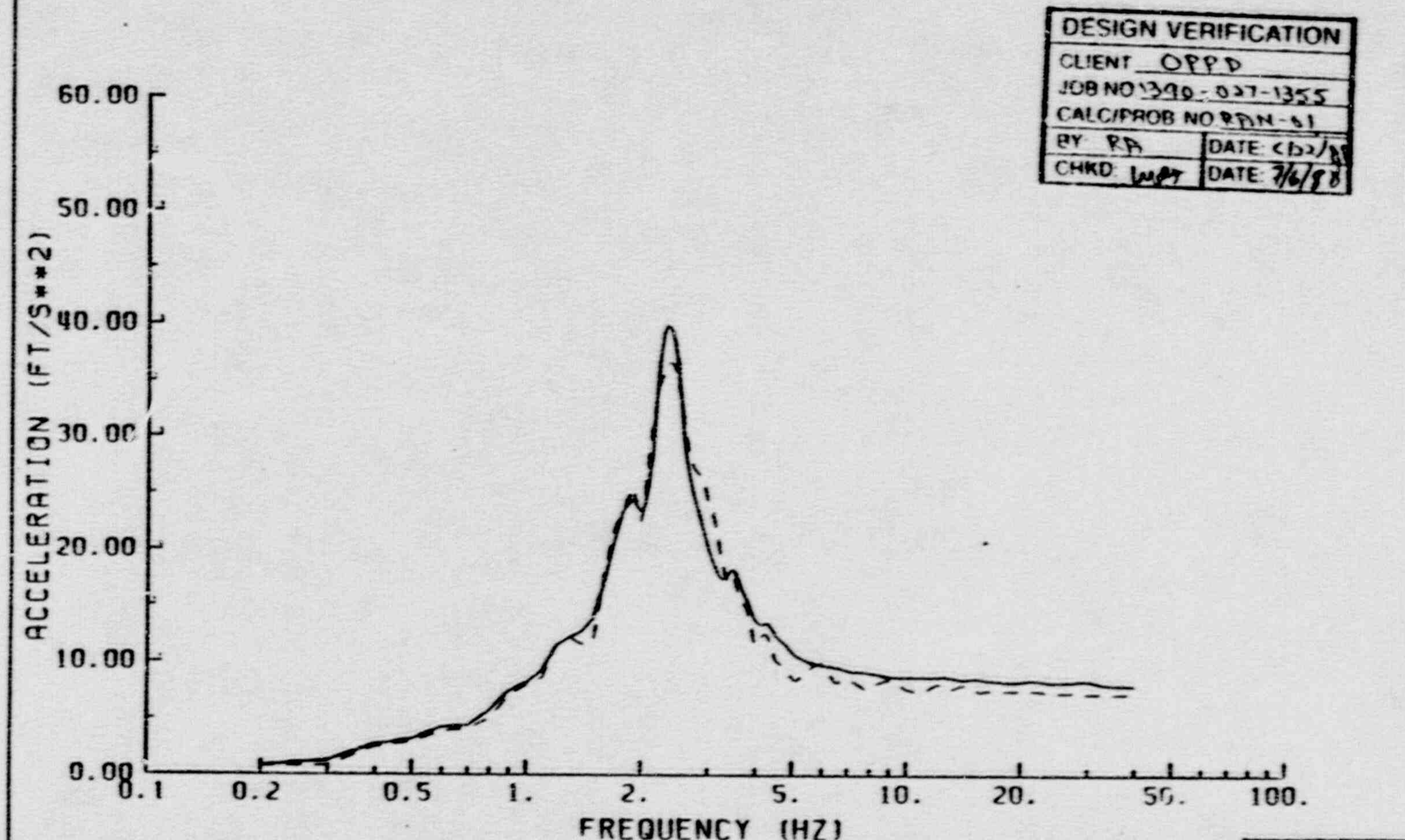
FIG. 5.4



SSG.FOR VERIFICATION/ PROBLEM 1, RUN 2
OPPD, AUX. BLDG., ELEV. 1044, C.G., N-S DIRECTION
DAMP.= 4 PERCENT SOLID= SSG.FOR DASH= RESPEC

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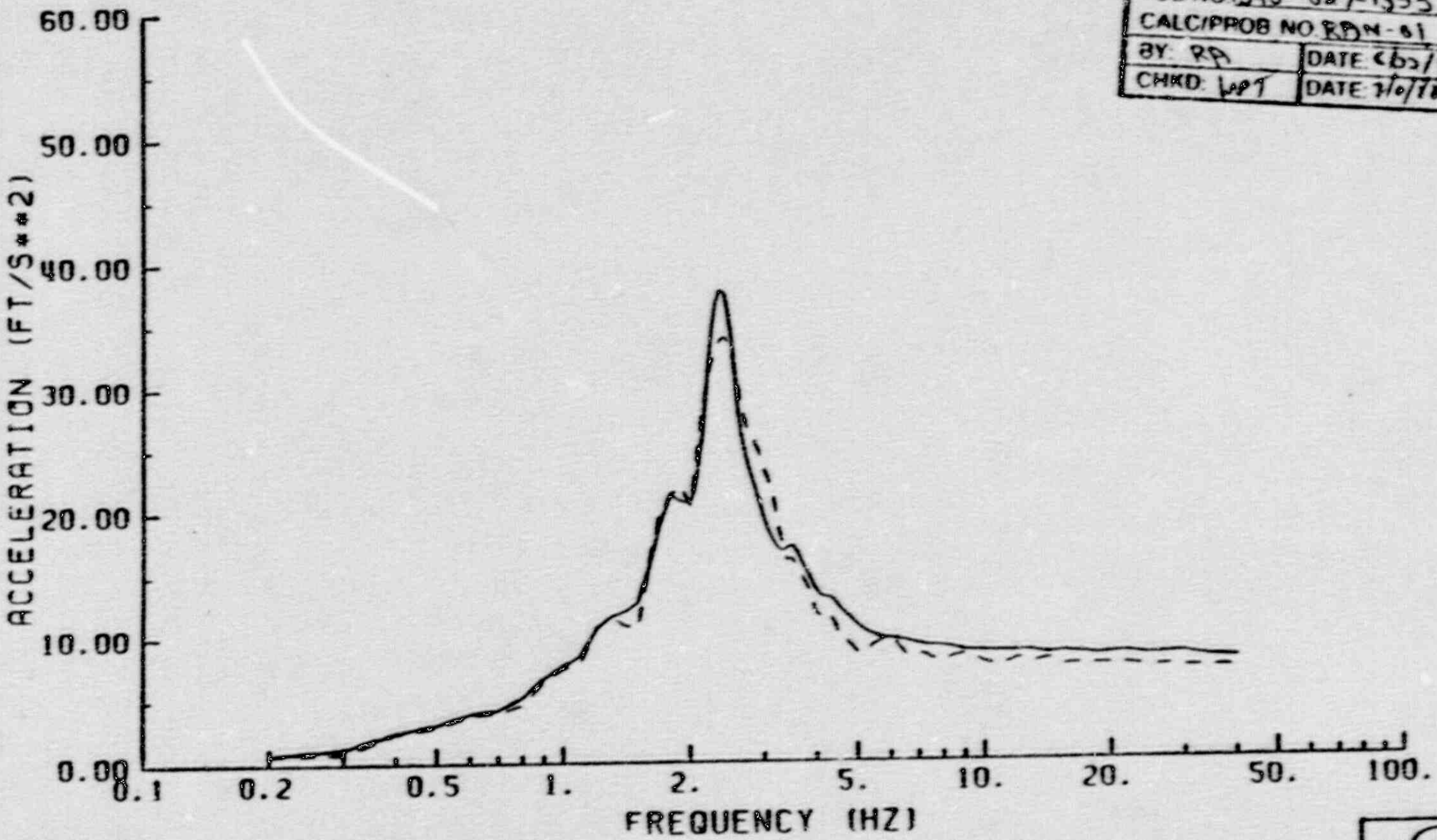
FIG. 5.5

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 390-027-1355	
CALC/PROB NO. RDN-01	
BY: RA	DATE 6/02/88
CHKD: WPT	DATE 7/0/78



SSG.FOR VERIFICATION/ PROBLEM 1, RUN 1
OPPD, AUX. BLDG., ELEV. 1044, C.G., N-S DIRECTION
DAMP. = 5 PERCENT SOLID= SSG.FOR DASH= RESPEC

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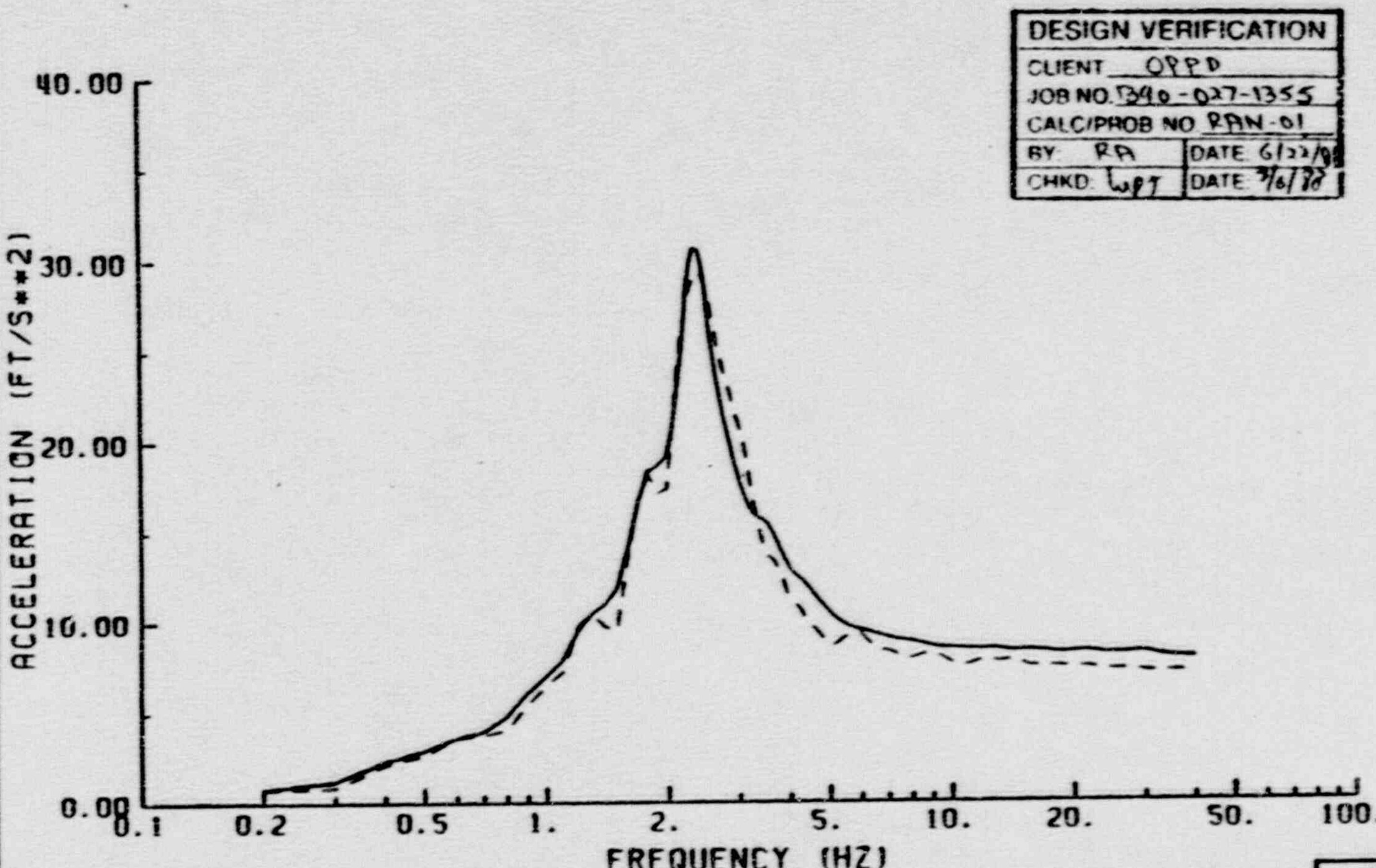
FIG. 5.6



SSC.FOR VERIFICATION/ PROBLEM 1, RUN 3
OPPD, AUX. BLDG., ELEV. 1044, C.G., N-S DIRECTION
DAMP. = 7 PERCENT SOLID= SSC.FOR DASH= RESPEC

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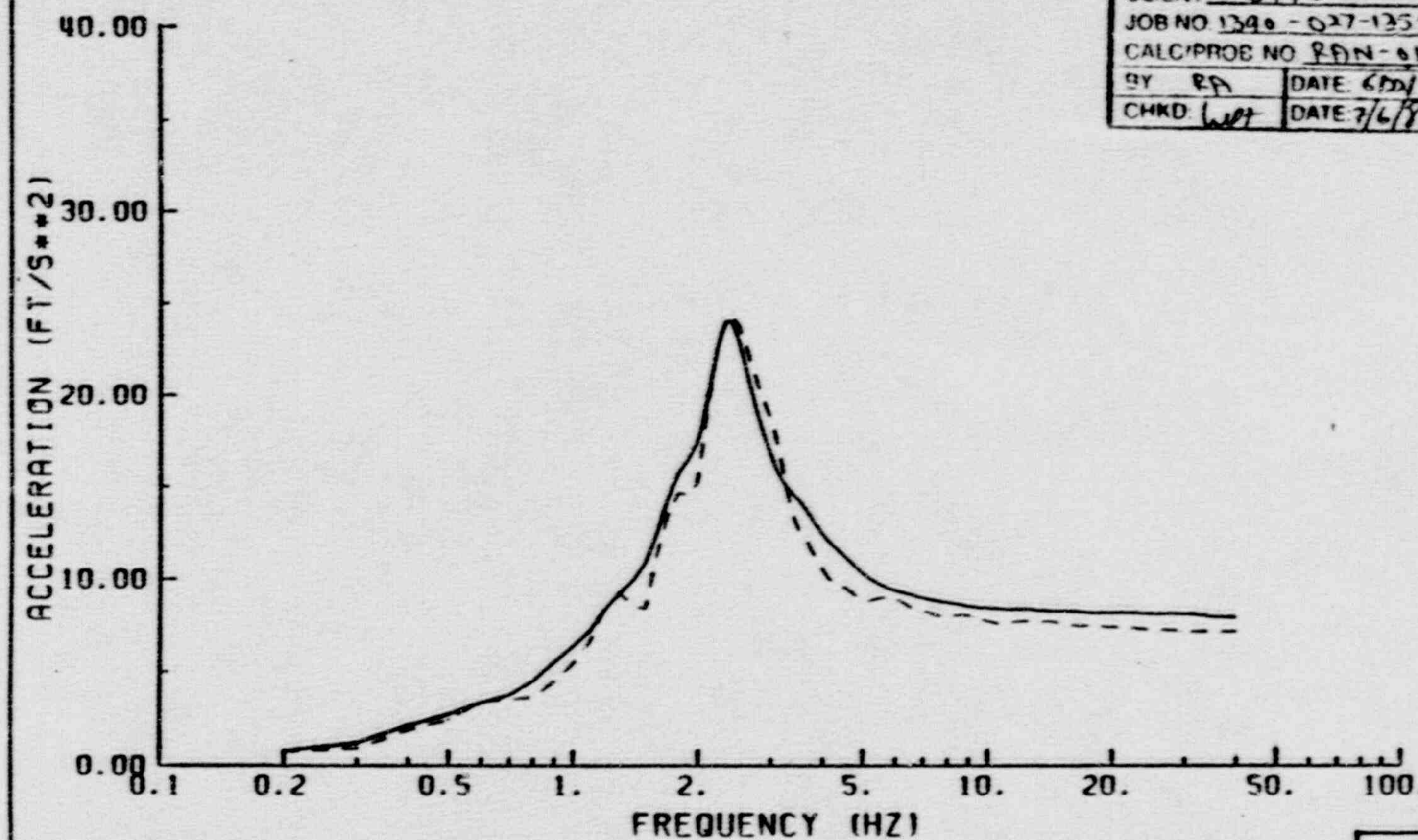
FIG. 5.7

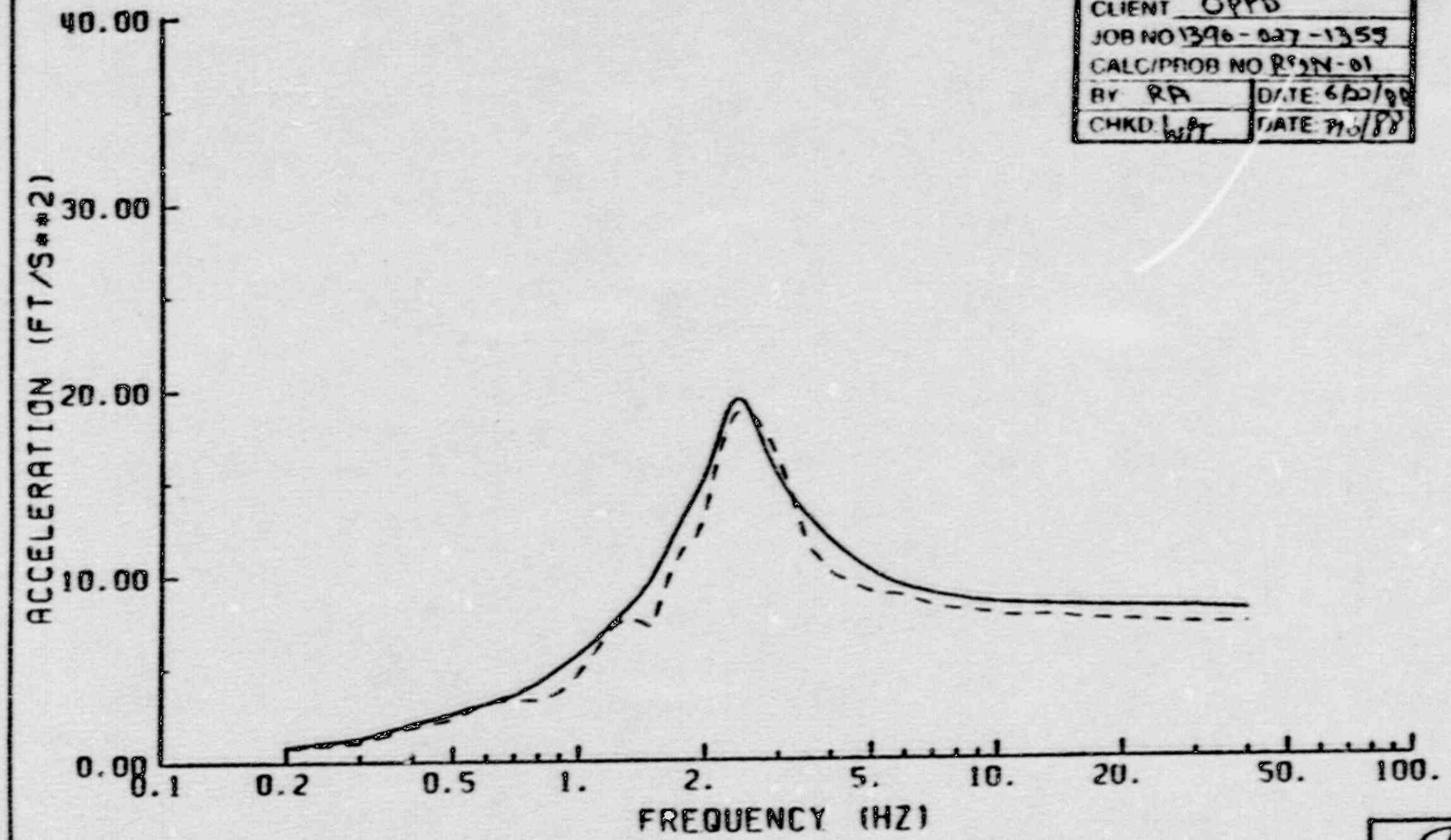
DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO. 1390-027-1355	
CALC/PROB NO. RAN-01	
BY RA	DATE 6/30/98
CHKD WET	DATE 7/6/98



SSG.FOR VERIFICATION/ PROBLEM 1, RUN 3
OPPD, AUX. BLDG., ELEV. 1044, C.G., N-S DIRECTION
DAMP.= 10 PERCENT SOLID= SSG.FOR DASH= RESPEC

FIG. 5.8

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO 1396-027-1355	
CALC/PROB NO R°2N-01	
BY RA	DATE: 6/22/88
CHKD: WJT	DATE: 7/16/88



SSC.FOR VERIFICATION/ PROBLEM 1, RUN 3
OPPD, AUX. BLDG., ELEV. 1044, C.C., N-S DIRECTION
DAMP.= 15 PERCENT SOLID= SSC.FOR DASH= RESPEC

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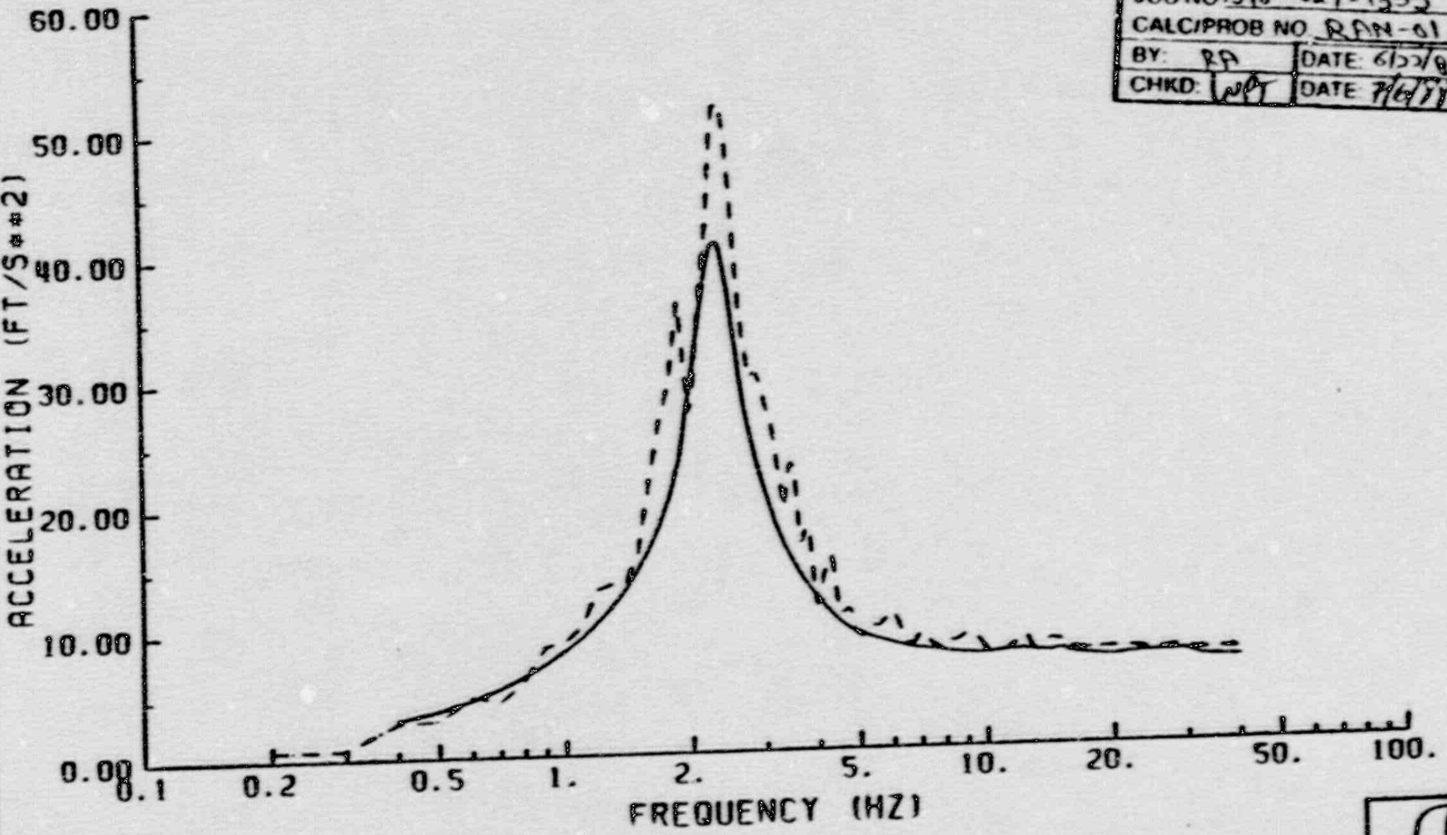
Fig. 5.9

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO 1390-027-1355	
CALC/PROB NO RAN-01	
BY: RA	DATE 6/22/88
CHKD: WPT	DATE 7/6/88



SSG.FOR VERIFICATION/ PROBLEM 2, RUN 1
OPPD, AUX. BLDG., ELEV. 1044, C.G., N-S DIRECTION
DAMP.= 2 PERCENT SOLID= SSG.FOR DASH= RESPEC

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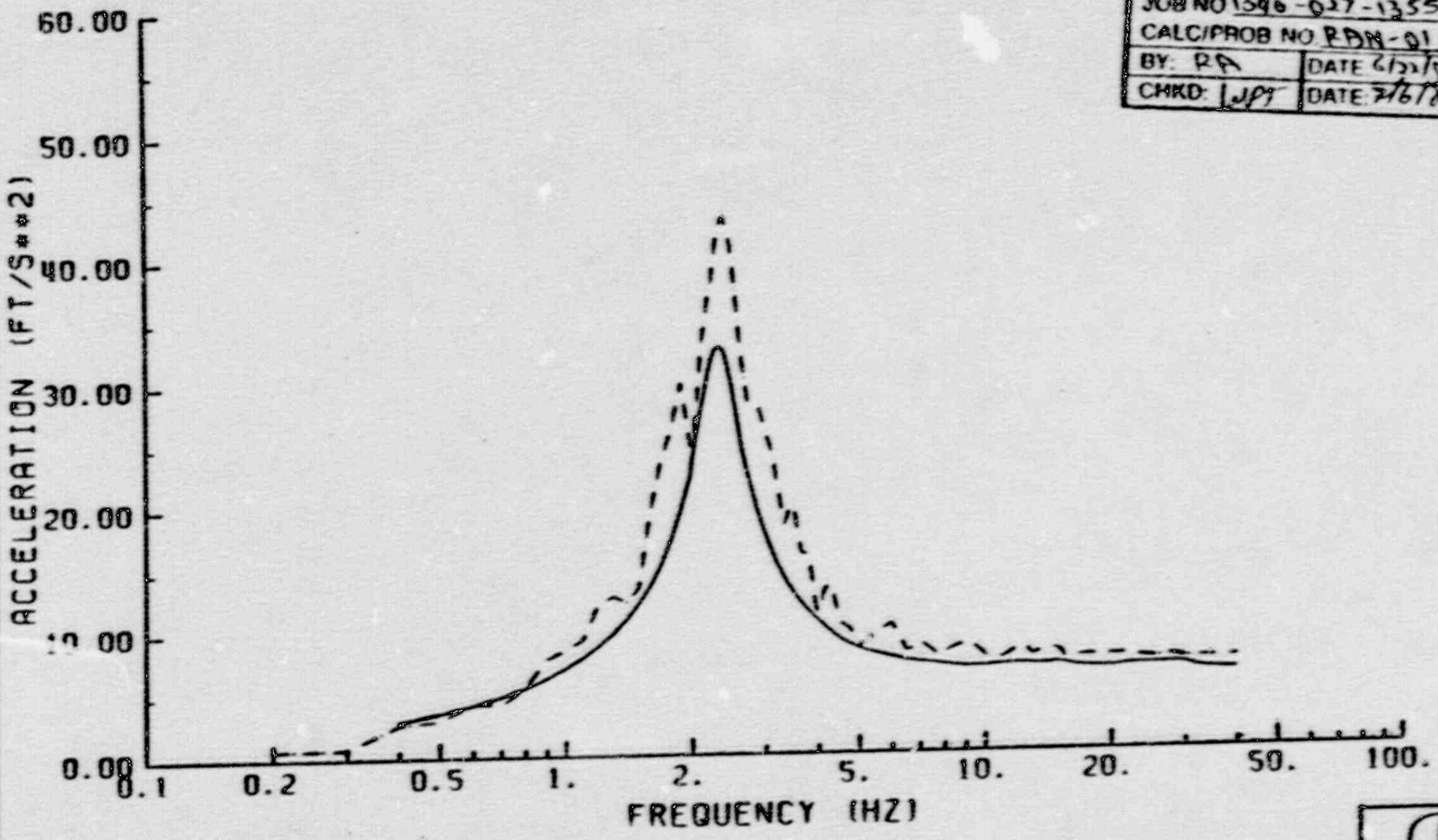
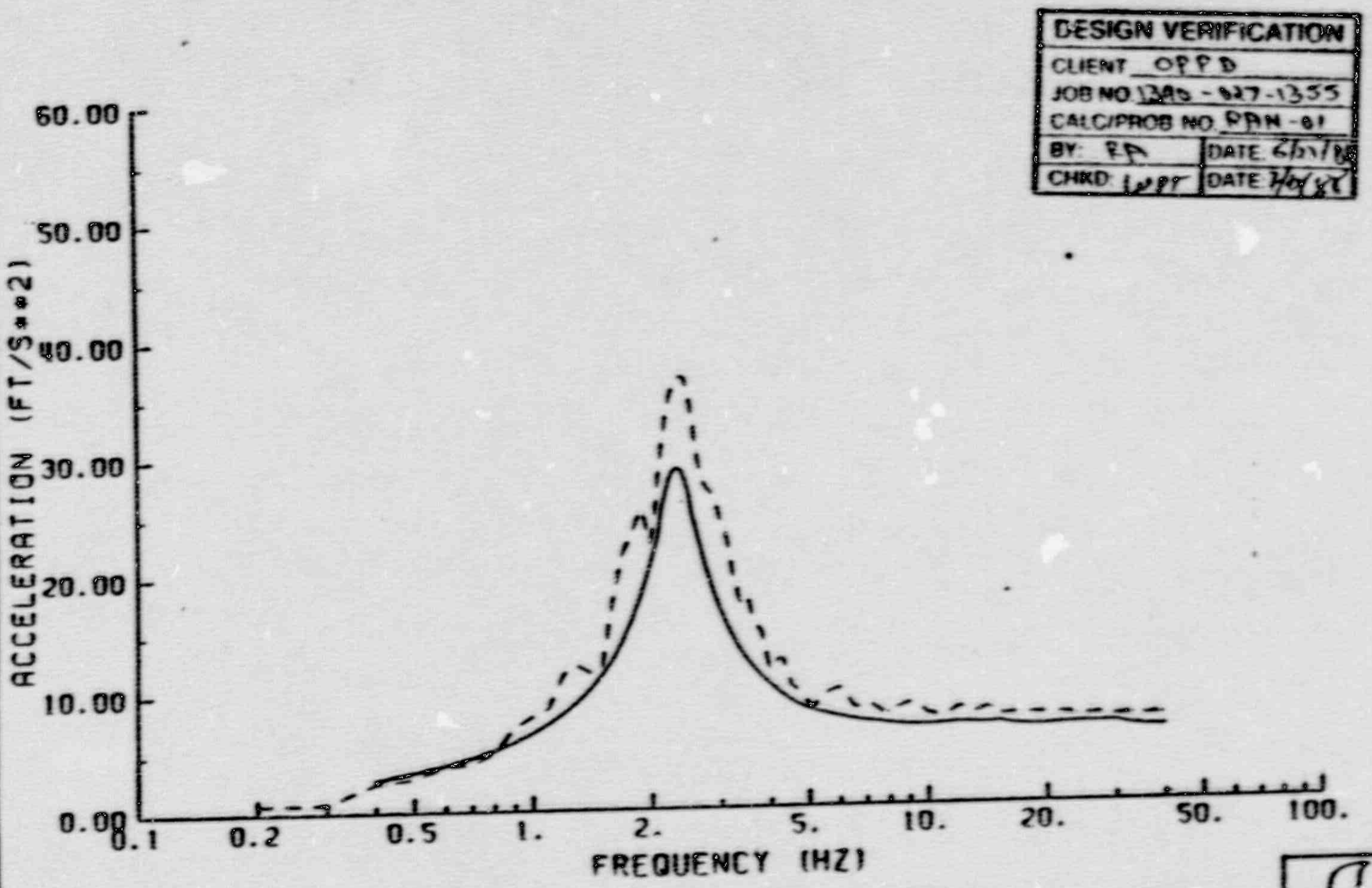
FIG. 5.10

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO 1390-027-1355	
CALC/PROB NO RAM-01	
BY: RA	DATE 6/22/88
CHKD: JPT	DATE 7/6/88



SSC.FOR VERIFICATION/ PROBLEM 2, RUN 2
OPPD, AUX. BLDG., ELEV. 1044, C.G., N-S DIRECTION
DAMP.= 3 PERCENT SOLID= SSC.FOR DASH= RESPEC

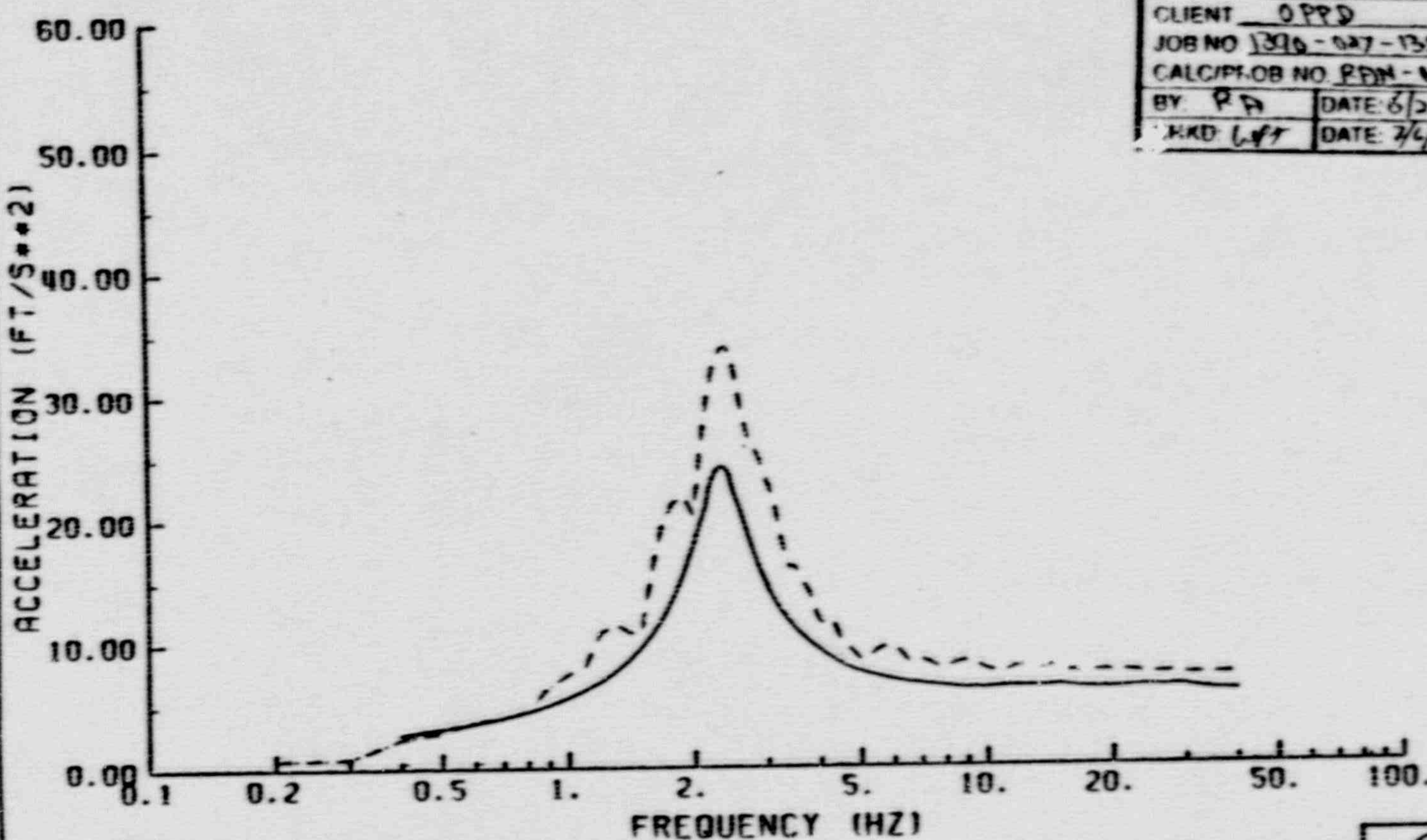
FIG. 5.11



SSG.FOR VERIFICATION/ PROBLEM 2, RUN 2
OPPD, AUX. BLDG., ELEV. 1044, C.G., N-S DIRECTION
DAMP.= 4 PERCENT SOLID= SSG.FOR DASH= RESPEC

Fig. 5.12

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO 1390-027-1355	
CALC/PROB NO RDM-81	
BY RA	DATE 6/22/88
CHKD LAT	DATE 7/6/88



SSG.FOR VERIFICATION/ PROBLEM 2, RUN 1
OPPD, AUX. BLDG., ELEV. 1044, C.G., N-S DIRECTION
DAMP.= 5 PERCENT SOLID= SSG.FOR DASH= RESPEC

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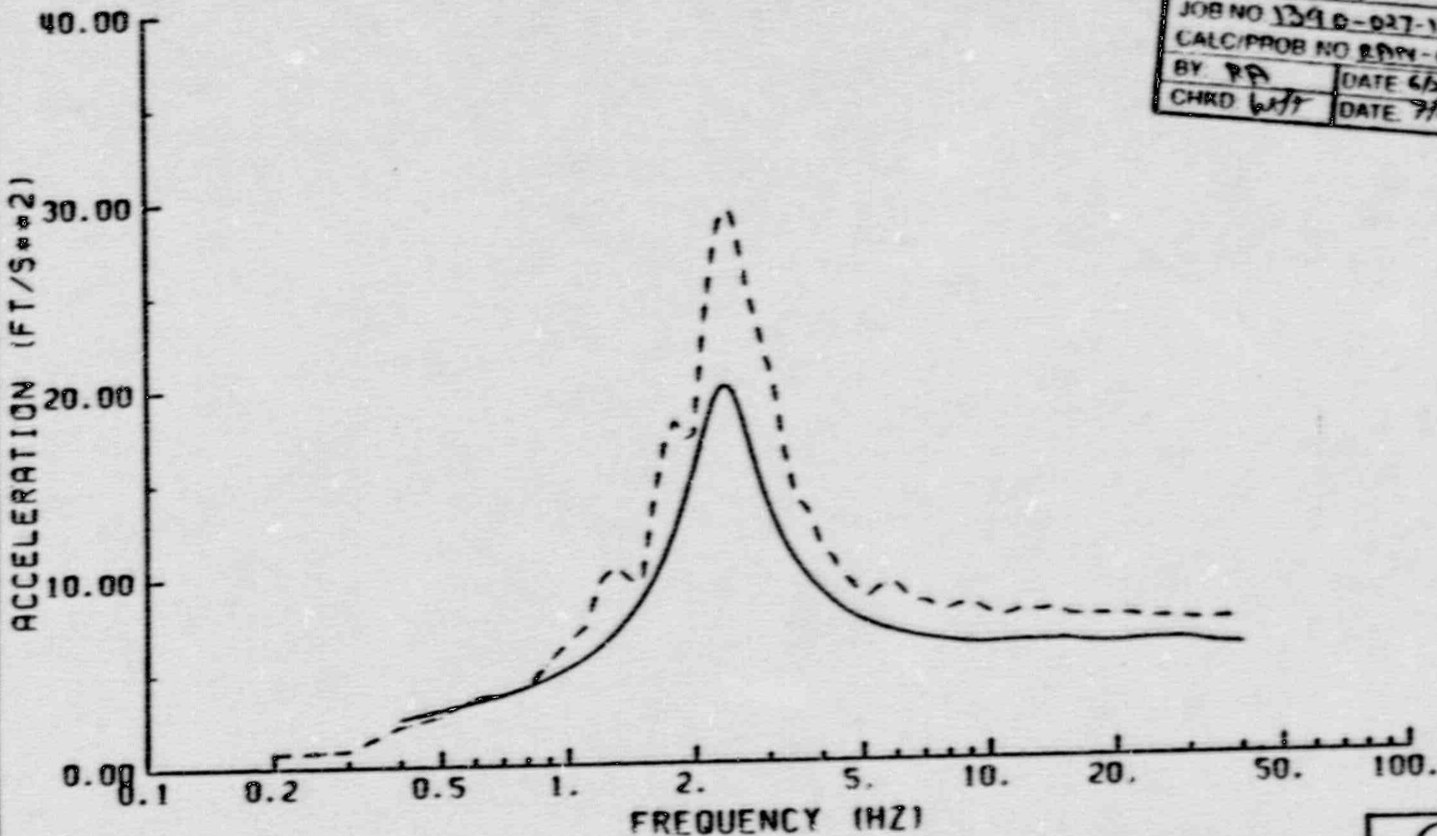
FIG. 5.13



DESIGN VERIFICATION
CLIENT OPPD
JOB NO 1390-027-1355
CALC/PROB NO
BY RA DATE
CHKD DATE

SSC.FOR VERIFICATION/ PROBLEM 2, RUN 3
OPPD, AUX. BLDG., ELEV. 1044, C.G., N-S DIRECTION
DAMP.= 7 PERCENT SOLID= SSC.FOR DASH= RESPEC

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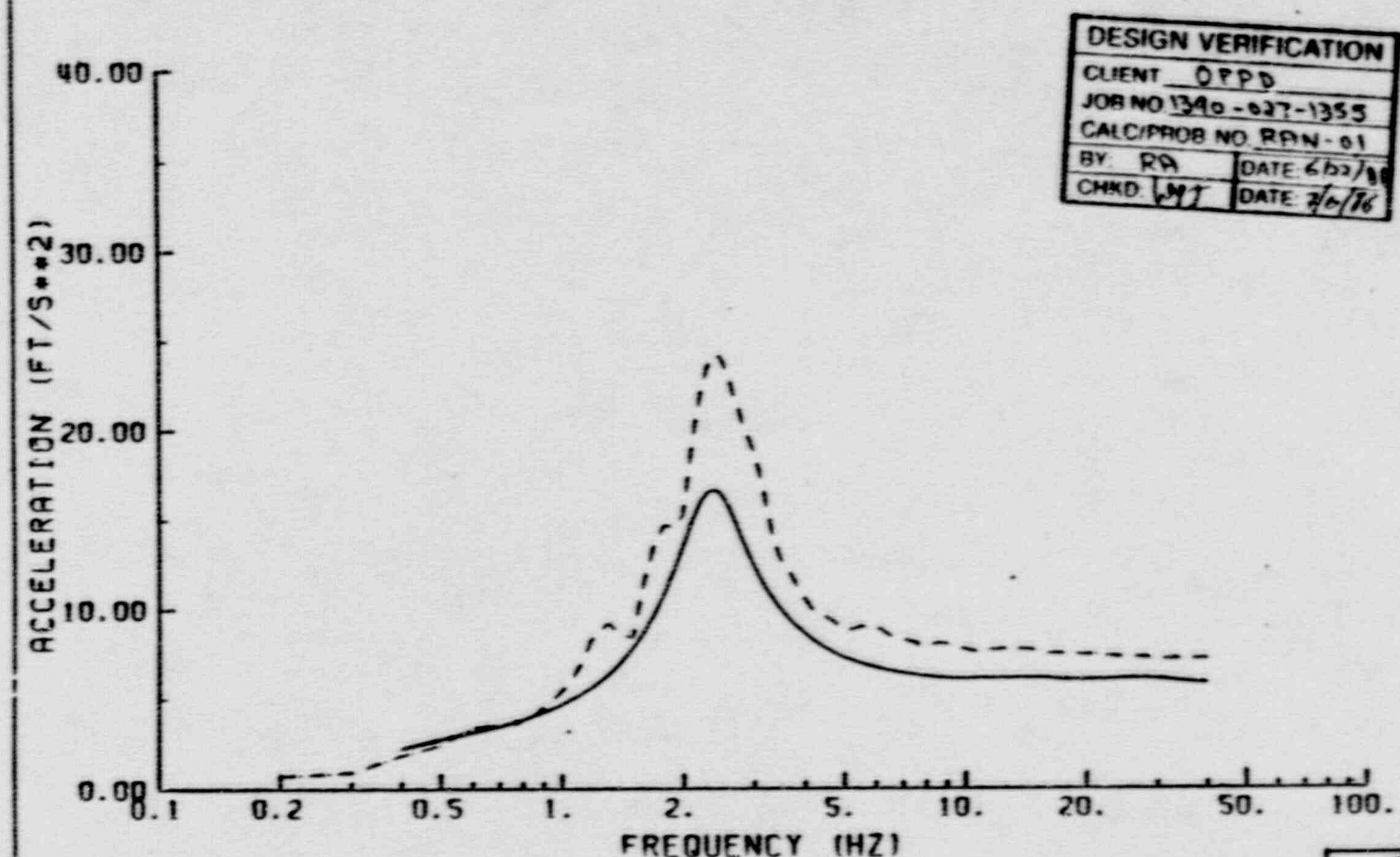
FIG. 5.14



SSG.FOR VERIFICATION/ PROBLEM 2, RUN 3
OPPD, AUX. BLDG., ELEV. 1044, C.G., N-S DIRECTION
DAMP. = 10 PERCENT SOLID= SSG.FOR DASH= RESPEC

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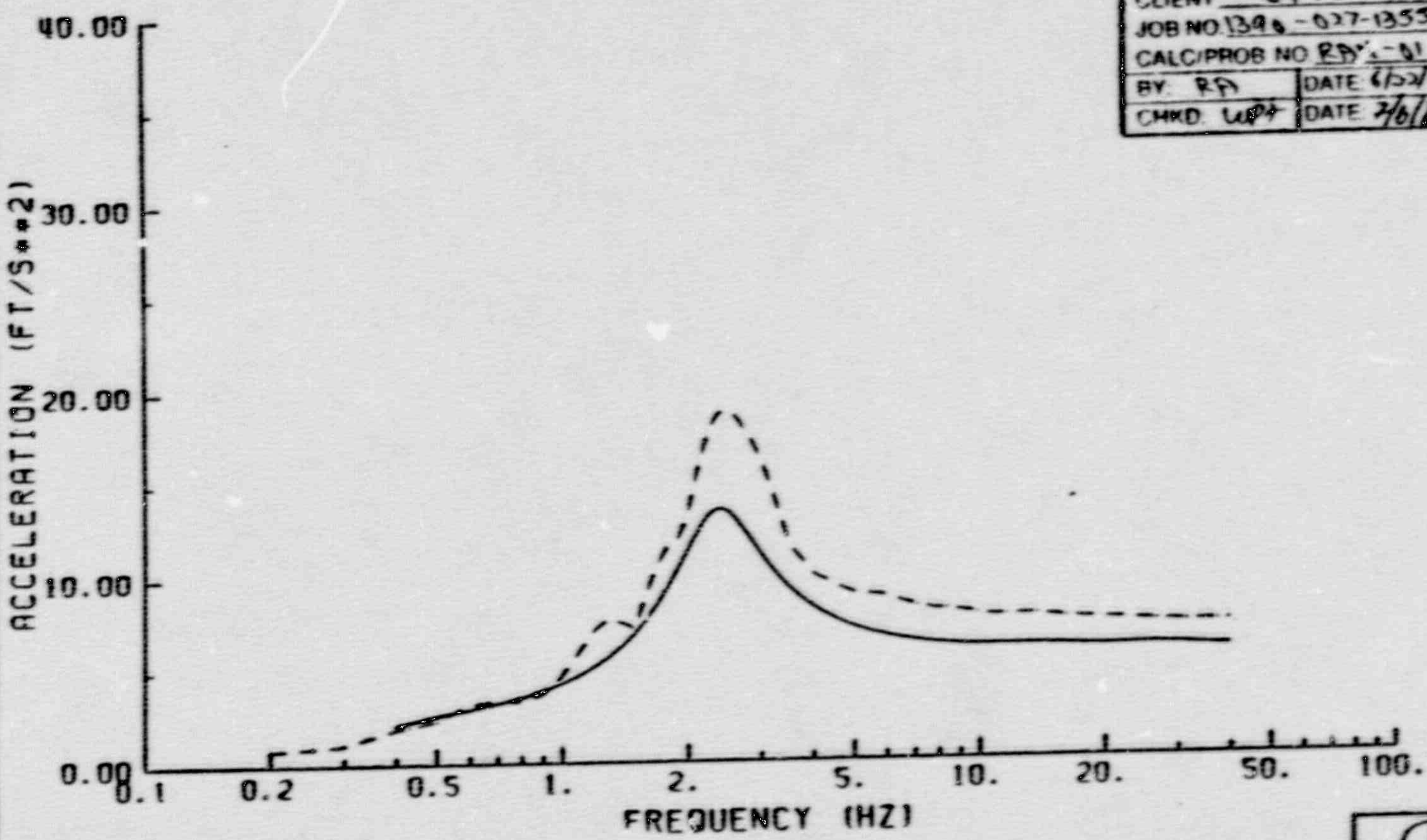
FIG. 5.15

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO 1396-027-1353	
CALC/PROB NO RDY-01	
BY: RA	DATE 6/22/88
CHKD: WP	DATE 7/6/88



SSC.FOR VERIFICATION/ PROBLEM 2, RUN 3
OPPD, AUX. BLDG., ELEV. 1044, C.G., N-S DIRECTION
DAMP.= 15 PERCENT SOLID= SSC.FOR DASH= RESPEC

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5.2 VERSION 2

Source listing for version 2 is contained in CRL # RAN-01-19.

CRL # associated with test problems are as follows:

Test Problem #	CRL #
1	RAN-01-20
2	RAN-01-21
3	RAN-01-22
4	RAN-01-23
5	RAN-01-24

Verification of version 2 is as follows:

(1) Output response spectra at 3% damping (CRL # RAN-01-20) is same as the output response spectra at 3% damping (CRL # RAN-01-12). This verifies version 2 with respect to version 1.

(2) In test problem 4, input spectra values are specified and are 0.6667 times the input spectra for test problem 1. From CRL* RAN-01-20 and RAN-01-23, it is seen that:

(1) Input PSDF for test problem 4 is $(0.6667)^2$ * Input PSDF for test problem 1, and

(2) Output spectra at 3% damping for test problem 4 is 0.6667 times the output spectra at 3% damping for test problem 1.

Sample of hand calculations to support above two statements is as follows.

<u>Statement (1)</u>

FREQ. HZ.	PSDF From Test Problem 1	PSDF From Test Problem 4	$(0.6667)^2$ x PSDF From Test Prob. 1
2.5	0.51924×10^{-1}	0.23080×10^{-1}	0.23080×10^{-1}
5.0	0.14351×10^{-1}	0.63787×10^{-2}	0.63789×10^{-2}
7.5	0.39458×10^{-2}	0.17538×10^{-2}	0.17539×10^{-2}

Statement (2)

FREQ (HZ)	RS From Test Problem 1	RS From Test Problem 2	0.6667 x RS From Test Problem 1
2.5	0.29974×10^2	0.19984×10^2	0.19984×10^2
5.0	0.83588×10^1	0.55728×10^1	0.55728×10^1
7.5	0.70591×10^1	0.47063×10^1	0.47063×10^1

(3) SRSS combination rule is verified as follows.

Freq. (Hz)	RS From Test Problem 1	RS From Test Problem 2	0.6667 x RS From Test Problem 3	SRSS by Hand Calculation	RS From Test Problem 5
2.5	0.29974×10^2	0.28280×10^1	0.47796×10^0	0.30111×10^2	0.30111×10^2
5.0	0.83588×10^1	0.66526×10^0	0.79817×10^0	0.84231×10^1	0.84231×10^1
7.5	0.70591×10^1	0.50578×10^0	0.28517×10^0	0.70829×10^1	0.70829×10^1
15.0	0.69778×10^1	0.54229×10^0	0.31079×10^0	0.70057×10^1	0.70051×10^1
40.0	0.62170×10^1	0.46390×10^0	0.18212×10^0	0.62370×10^1	0.62369×10^1

(4) By observation from Run # RAN-01-24, Test Problem 5, the output spectra is same for both locations. This verifies the option to generate output spectra at more than one

location.

0	RA	6/23/88	WDT	7/1/88	
REV	BY	DATE	CHECKED	DATE	IMPELL CORPORATION

JOB NO 1390-027-1355

CALC NO RAN-01

5.3 VERSION 3

Source listing for version 3 is contained in CRL # RAN-01-25

CRL # RAN-01-26 is test problem 1. Output spectra is same as the output spectra in CRL # RAN-01-27. This verifies version 3 with respect to version 2.

CRL # RAN-01-27 is test problem 2. Printout of Tape 7 corresponding to test problem 2 is contained in CRL # RAN-01-28. This printout contains PSDF of input spectra in following order

(1) PSDF corresponding to average of 2% and 5% input spectra for first direction

(2) PSDF Corresponding to average of 2% and 5% input spectra for second direction. Input spectra for second direction is same as first direction.

(3) PSDF corresponding to average of 2% and 5% input spectra for third direction. Input spectra for third

direction is 0.6667 times the second direction.

(4), (5) & (6) PSDF corresponding to 2% input spectra in same order as above.

(7), (8) & (9) PSDF corresponding to 5% input spectra in same order as above.

By observation PSDF (1) is same as input PSDF in CRL # RAN-01-20, and PSDF (3) is same as input PSDF in CRL # RAN-01-23. This verifies the option to calculate input PSDF only.

6. USER GUIDE FOR RANDOM VERSION 3

Card 1

Columns	Format	Data	Description
1-5	I5	NOPT	Must be = 2

Card 2

Columns	Format	Data	Description
1-5	I5	NSTART	Must be = 1
6-10	I5	NSTOP	Must be = 3

Card 3

Columns	Format	Data	Description
1-5	I5	NOF	No. of Output Freq.

Card 4

Columns	Format	Data	Description
1-5	I5	NSET	No. of Output spectra locations

Card 5

Columns	Format	Data	Description
1-5	I5	NDIF	≠ 1: if Input freqs. same as output freqs. = 1 otherwise

REV	BY	DATE	CHECKED	DATE
0	RA	7/10/88	AHZ	7.10.88

IMPELL CORPORATION

JOB NO 1390-027-1355

CALC NO RAN-01

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Card 6

Include only if NDIF (card 5) = 1

Columns	Format	Data	Description
1-5	I5	KHR	≠1 : Unit of output freqs. = Hz 1 = Unit of output freqs. = rad/sec.
6-45	40A1	FORM	Format to read output freq.

Card 7

Include only if NDIF (card 5) = 1

As many cards as required to input NOF (card 3) no. of output frequencies in format "FORM" (card 6)

Repeat cards 8 through 26 NSET (card 4) Times

Card 8

Columns	Format	Data	Description
1-5	I5	NTFHR	= 1 : if freqs. in Hz for Transfer function (TF) ≠ 1 : if freqs in rad/sec for TF
6-10	I5	NTFCR	= 1 : Complex T.F. ≠ 1 : Real TF

Card 9

Input spectra can be specified for three translational directions (X, Y and Z). Input spectra for a direction can be same as previous direction in the same set, or same as the one specified for the direction in previous set or new.

Columns	Format	Data	Description
1-5	I5	NDIRI	No. of directions for input spectra
6-10	I5	ICOD(1)	= 0 if spectra in X direction is same as last set = 1 new spectra
11-15	I5	ICOD(2)	= 0 if spectra in Y dir is same as previous set = 1: new spectra = 2: spectra in Y dir. is same as X dir.
16-20	I5	ICOD(3)	= 0 if spectra in Z dir. is same as previous set = 1: new spectra = 2: spect. in Z dir. is same as Y dir

0	RA	7/10/88	MHZ	7/10/88
REV	BY	DATE	CHECKED	DATE

IMPELL CORPORATION

JOB NO 1390-027-1355

CALC NO RAN-01

For input spectra in each direction (NDIRI times), input cards 10 to 20 Separate set of input is required if different values of ICOD
For ICOD=1, input following cards 10 to 20

Card 10

Columns	Format	Data	Description
1-5	E5.2	TAU	Strong motion duration in seconds

Card 11

Columns	Format	Data	Description
1-5	I5	MODDAMP	= 1 always

Card 12

The input spectra in a direction can be specified as average or envelope of no. of spectra. This feature is useful, if input spectra is available at different dampings.

1-5	I5	NIS	=1 : input spectra is specified directly
			≠1 : input spectra is "average or "envelope" of NIS spectra

REV	BY	DATE	CHECKED	DATE
0	RA	7/10/88	HMZ	7/10/88

IMPELL CORPORATION

JOB NO 1390-027-1355
CALC NO RAN-01

Card 12 (Continued)

6-10	I5	NEVAV	= 1 : Input spectra is envelope of NIS spectra
			0 : Input spectra is average of NIS spectra

Card 13

1-5	I5	NIF	No. of Freqs for input spectra

Card 14

1-5	I5	KMAX	No. of Iterations for calculating PSDF
6-10	I5	NCOUNT	No. of Iterations skipped between calculating Peak Factors

Card 15

1-5	I5	NRNG	No. of Tolerance Ranges

REV	BY	DATE	CHECKED	DATE
0	RA	7/10/88	MMZ	7/10/88

IMPELL CORPORATION

JOB NO 1390-027-1355

CALC NO RAN-01

Card 16

Repeat NRNG Times

Columns	Format	Data	Description
1-5	I5	NLO(I)	Freq. No. in input spectra for lower bound on tolerance i
6-10	I5	NUP(I)	Freq No. in input spectra for upper bound on tolerance i
11-15	E5.1	TOL(I)	Tolerance i

Card 17

1-5	I5	IPR	=1 print input spectra

Repeat Cards 18 to 20 NIS (Card 12) times

Card 18

1-10	E10.4	ZETA	Damping of Input Spectra

Card 19

1-10	F10.0	SCALE	Scale factor
11-50	40A1	FORM	Format for reading Input spectra

REV	BY	DATE	CHECKED	DATE
0	RA	7/10/88	HMZ	7/10/88

IMPELL CORPORATION

JOB NO 1390-027-1355

CALC NO RAN-01

Card 20

As many cards as required to read input spectra, pairwise, in frequency-spectral pairs, in format specified in card 19.

For ICOD = 2, following cards are required.

Card 10

1-10 F10.0 FACTOR Input spectra is FACTOR x input spectra in previous directions.

Cards 11 to 20 are not required for ICOD = 2

For ICOD = 0, cards 10 to 20 are not required.

Repeat cards 21 to 24 NDIRI times.

Card 21

1-80 40A2 TITL Title for Transfer Function

REV	BY	DATE	CHECKED	DATE
0	RA	7/11/88	MHZ	7/10/88

IMPELL CORPORATION

JOB NO 1390-027-1355

CALC NO RAN-01

Card 22

Columns	Format	Data	Description
1-5	I5	NTFP	No. of Transfer Function Values
6-21	E16.8	V(2)	Critical Frequency
22-37	E16.8	STEP	Frequency step

Card 23

1-5	I5	IREW	1 = Rewind Tape ≠1 : Do not rewind
6-10	I5	IPR	1 = Print Transfer functions ≠1 Do not Print
11-51	40A1	FORM1	Format for Transfer functions

Card 24

1-5	I5	IPR	1 = Print PSDF at output location ≠1 Do not Print output PSDF

REV	BY	DATE	CHECKED	DATE		JOB NO	PAGE
0	RA	7/10/88	MMZ	7/10/88	IMPELL CORPORATION	JOB NO 1390-027-1355 CALC NO RAN-01	46 OF 51

Card 25

1-5 I5 NOS No. of damping values for output spectra

Card 26

1-20 10E5.2 ZETAD Damping values for output spectra.

NOTE: Transfer functions are read from TAPE 4, in format 'FORMI' specified in Card 23.

REV	BY	DATE	CHECKED	DATE		
0	RA	7/10/88	MMZ	7/10/88	IMPELL CORPORATION	JOB NO 1390-027-1355 CALC NO RAN-01 PAGE 47 OF 51

7. REFERENCES

1) SPECGEN Verification File Version March 1988 Rev 0 (Preliminary). A Computer Program for the Damping Ratio Extrapolation of Acceleration Response Spectra.

2) Clough, R.W. and Penzien, J., "Dynamics of Structures," McGraw Hill Book Company, Copyright © 1975

(3) Impell calc. AUX-03 "SSI Analysis and Design Spectra Generation for Aux, Internal and Containment Structures, SSE Conditions," Rev. 0., Client OPPD, Project Fort Calhoun, Job# 1390-027-1355.

(4) "CLASSI", Impell standard program. Version 0.0. Dated 6/19/86.

(5) Impell calc INT-05, "OBE Response Spectra For Intake Building," Rev. 0. Client OPPD Project Fort Calhoun, Job No. 1390-027-1355

(6) "RESPEC", Impell Standard Program, Version 10/01/75.

(7) Vax Version of Project Specific Program RESPEC, Calc THG-1, 1390-027-1355, Rev. 0.

(8) "EDSPLOT", Impell Standard Program Version May 1987.

REV	BY	DATE	CHECKED	DATE
1	RA	1/6/89	HMZ	2/7/89
0	RA	6/22/88	WPT	7/6/88

IMPELL CORPORATION

JOB NO 1390-027-1355

CALC NO RRN-01

IMPELL

COMPUTER PROGRAM RUN LOG
(OPTIONAL)

CLIENT OPPD PROJECT FORT CALHOUN JOB NUMBER(S) 1390-027-1355

PROGRAM

DESIGN VERIFICATION	
CLIENT OPPD	
JOB NO 1390-027-1355	
CALC/PROB NO RAN-01	
BY: RA	DATE 6/88
CHKD: WPV	DATE 7/88

VERSION	RUN NO	DATE	PROJECT TASK	BY
RESPEC	RAN-01-01	6/22/88	Response Spectra for Artificial T. H.	RA
RESPEC	RAN-01-02	6/22/88	Response Spectra at CM, 1044' 1% Co	
RESPEC	RAN-01-03	6/22/88	Response Spectra at CM, 1044': 2,3,4,5,7,10, 8% Co	RA
RANDOM-1	RAN-01-04	6/22/88	Source Version 1	RA
RANDOM-1	RAN-01-05	6/22/88	Test Problem 1 - Run 1	
RANDOM-1	RAN-01-06	6/22/88	Test Problem 1 - Run 2	RA
RANDOM-1	RAN-01-07	6/22/88	Test Problem 1 - Run 3	
EDSPLOT	RAN-01-08	6/22/88	Test Problem 1 - Run 1	RA
EDSPLOT	RAN-01-09	6/22/88	Test Problem 1 - Run 2	RA
EDSPLOT	RAN-01-10	6/22/88	Test Problem 1 - Run 3	RA
RANDOM-1	RAN-01-11	6/22/88	Test Problem 2 - Run 1	RA
RANDOM-1	RAN-01-12	6/22/88	Test Problem 2 - Run 2	RA
RANDOM-1	RAN-01-13	6/22/88	Test Problem 2 - Run 3	RA
EDSPLOT	RAN-01-14	6/22/88	Test Problem 2 - Run 1	RA
EDSPLOT	RAN-01-15	6/22/88	Test. Problem 2 - Run 2	
EDSPLOT	RAN-01-16	6/22/88	Test Problem 2 - Run 3	RA

IMP[illegible]

COMPUTER PROGRAM RUN LOG
(OPTIONAL)

CLIENT OPPD PROJECT FORT CALHOUN JOB NUMBER(S) 1390-02-1355

PROGRAM ______

DESIGN VERIFICATION
CLIENT OPPD
JOB NO 1390-[illegible]
CALC/PROB NO RAN-0[illegible]
BY: RA DATE 6/23/[illegible]
CHKD: [illegible] DATE 7/6/[illegible]

VERSION	RUN NO	DATE	PROJECT TASK	BY
RANDOM-1	RAN-01-17	6/22/88	Test Problem 1 - Run 4	RA
EDSPLOT	RAN-01-18	6/22/88	Test Problem 1 - Run 4	RA
RANDOM-2	RAN-01-19	6/23/88	Source - Version 2	RA
RANDOM-2	RAN-01-20	6/23/88	Test Problem 1 - Version 2	RA
RANDOM-2	RAN-01-21	6/23/88	Test Problem 2 "	RA
RANDOM-2	RAN-01-22	6/23/88	" " 3 "	RA
RANDOM-2	RAN-01-23	6/23/88	" " 4 "	RA
RANDOM-2	RAN-01-24	6/23/88	" " 5 "	RA
RANDOM-3	RAN-01-25	6/23/88	Source - Version 3	RA
RANDOM-3	RAN-01-26	6/23/88	Test Problem 1 Version 3	RA
RANDOM-3	RAN-01-27	6/23/88	" " 2 "	RA
RANDOM-2	RAN-01-28	6/23/88	" " 2 "	RA

ATTACHMENT 5
Theoretical Background Section of the Verification File
of the Impell Program SPECGEN
(Theoretical Basis of SPECGEN is used in the SASSI module RANDOM)

PROGRAM SPECIFICATIONS

SPECGEN
Version August 1988
Revision 0

A Computer Program for Damping Ratio Extrapolation of Acceleration Response Spectra

Prepared by: Alejandro Asfura — 10/3/88
Alejandro Asfura
Program Engineer
Date

Approved By: S. Esfandiari — 10/3/88
Sohrab Esfandiari
Section Manager
Date

PROGRAM SPECIFICATIONS

The purpose and scope of program SPECGEN, Version August 1988 are described below.

- **Program Function**

  The program SPECGEN, Version August 1988, uses a known set of acceleration response spectra for given damping ratios, to generate acceleration response spectra for any damping ratio. This is schematically shown in Figure 1.

  Figure 1: SPECGEN FUNCTION

  SPECGEN can use one or several response spectra as input to generate the additional response spectra.

- **Application**

  The main application of program SPECGEN can be found in old nuclear power plants where only floor response spectra for low damping ratios are available. If spectra for higher damping ratios are needed, and neither the ground input motion nor the structural models are available, then SPECGEN can be used to generate those new spectra without regenerating structural models and/or time-history analyses.

- **Limitations**

  The numerical errors in the methodology increase as the difference between the damping ratio of the known spectrum and the damping ratio of the target spectrum increases. Therefore, it is advised not to generate spectra for a very high (low) damping from a very low (high) damping spectrum (e.g., generate a 1[illegible] damping spectrum from a 1% damping spectrum).

- **Program Language**

  SPECGEN, Version August 1988, has been coded in FORTRAN 77 on the VAX/VMS Version 4.6 system.

- User Requirements

No special requirements are needed for the user. The input to the program is described in detail in the User's Manual.

- Program Design

Program SPECGEN, Version August 1988, is composed of a group of independent subroutines which are designed to perform specific functions. A brief description of each subroutine is provided below. Figure 2 provides a flow chart which shows how the various subroutines are linked together.

- Input and Output

The input consists of a set of control parameters, a set of known response spectra and a set of damping ratios defining the target spectra. The input data are input from tape 5. In addition to an echo of the input, the output consists of the final power spectral density function and the set of target spectra for the requested damping ratios. The output is written to tape 6 by the program. Output response spectra are also written to tape 7.

- Description of Subroutines

1. Program BEGIN

   - creates blank common for double precision variables
   - reads number of output frequencies, number of input frequencies, and number of output spectra to be generated

2. Subroutine SPECGEN

   - reads input data
   - echo prints input data
   - distributes tasks
   - writes results

3. Subroutine ORGW

   - organizes output frequencies in numerically ascending order

4. Subroutine GENR

   - uses input response spectrum, input frequencies and linear interpolation to generate input response spectrum (R) at output frequency points.

5. Subroutine PEAK

   - calculates peak factor using one of two possible methods
     a. Der Kiureghian [1]
     b. Vanmarcke [2]

6. Subroutine AROW

- generates one row of the A matrix

7. Subroutine MMULT

- performs matrix multiplication, TEMP = A S

8. Subroutine RKNEW

- calculates new spectrum values; RBAR = PF $\sqrt{TEMP}$

9. Subroutine CONV

- checks to see if specified tolerances are satisfied

10. Subroutine NEWS

- Calculates error factor at each frequency; E = $(R/RBAR)^2$
- calculates new PSDF; S = E S

11. Subroutine SAVES

- Saves resulting PSDF for each input response spectrum

12. Subroutine ENVAVG

- calculates the enveloped/average PSDF

13. Subroutine FACRNEW

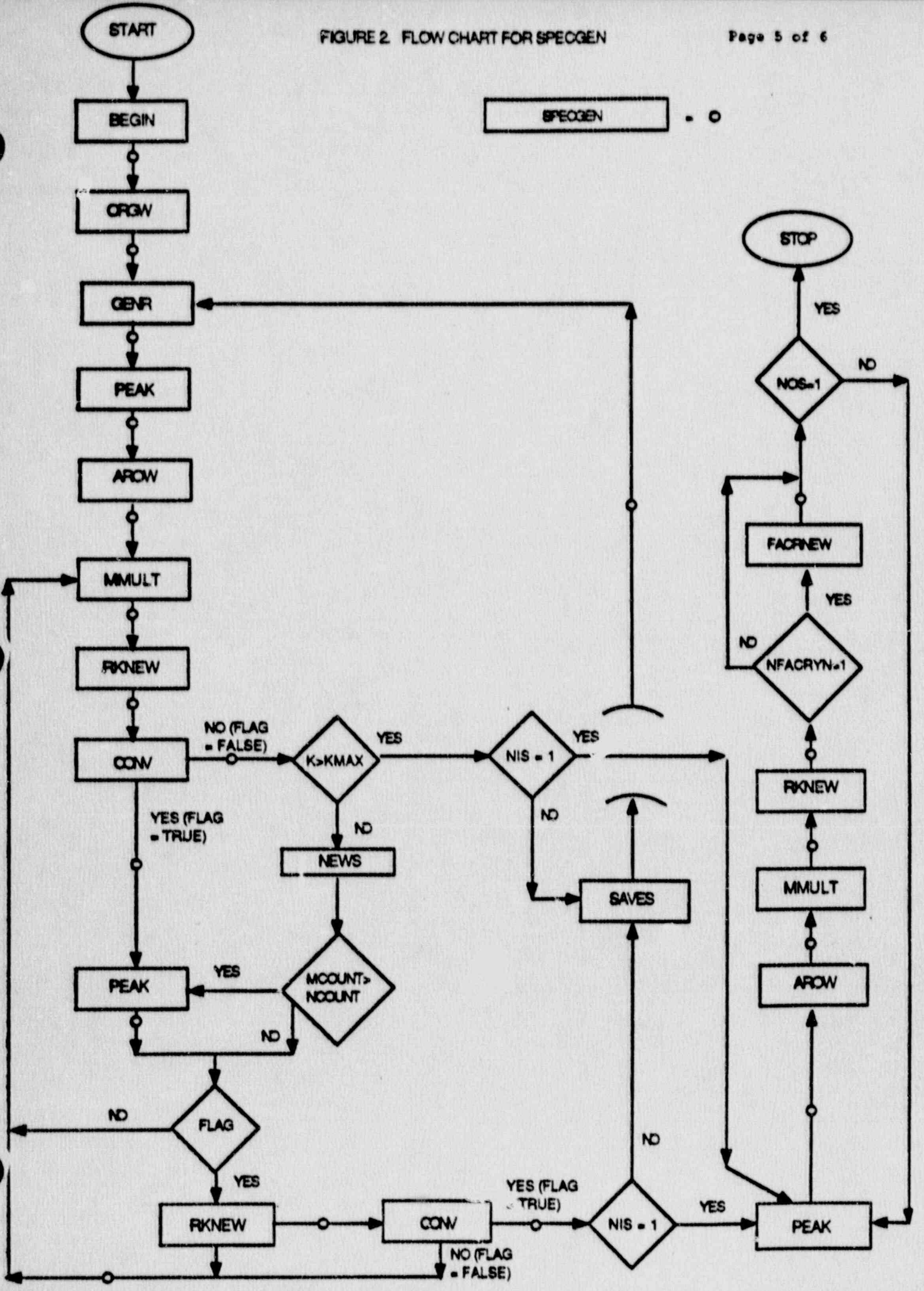
- calculates ratio of input ZPA to output ZPA. If the ratio is greater than one the subroutine multiplies(raises) the entire response spectrum by that ratio. Otherwise, the subroutine lowers the output spectrum exponentially from the spectrum value at frequency NFRQZPA, as defined by input, to the input ZPA value.

References

[1] Der Kiureghian, A., "Structural Response to Stationary Excitation," Journal of the Engineering Mechanics Division, ASCE, Vol. 106, No. EM6, Proc. Paper 15898, December, 1980, pp. 1195-1213.

[2] Vanmarcke, E.H. (1976) "Structural Response to Earthquakes," Chapter 8 of "Seismic Risk and Engineering, Decisions" C. Lomnitz and E. Rosenblueth, eds., Developments in Geotechnical Engineering, Vol. 15, Elsevier Scientific Publishing Company.

FIGURE 2. FLOW CHART FOR SPECGEN



APPENDIX A

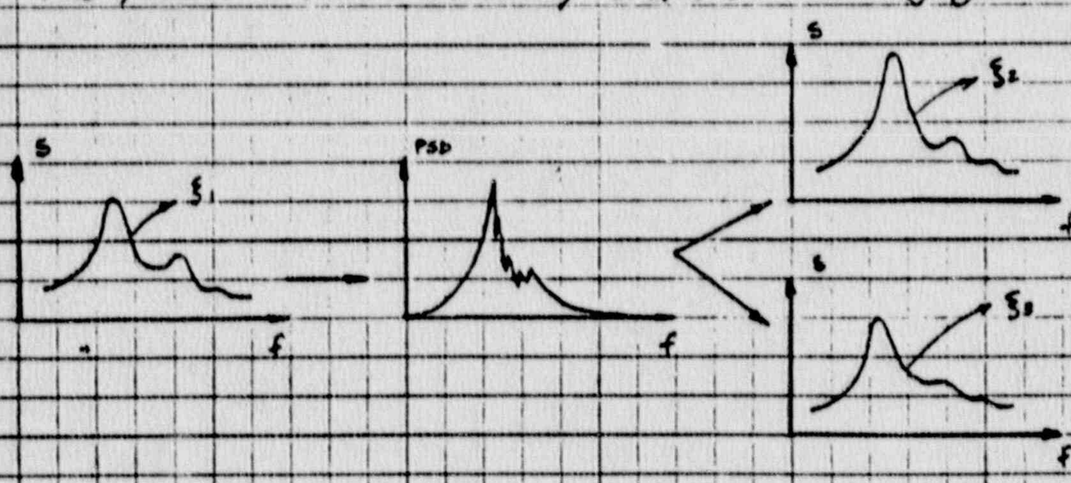
THEORETICAL DEVELOPMENT

Pages 1 - 30
(Incl. P 29A)

Appendix A. Theoretical Development

Methodology

To perform the extrapolation of acceleration response spectra, principles of random vibrations will be used. First, the known response spectra will be converted into a power spectral density function. The power spectral density function is a representation of the motion and it measures the energy content at each frequency. This function is independent of damping. Once the power spectral density function is known, again using random vibration theory, the response spectra for any damping rates can be calculated from it. The process is schematically shown in the figure below:



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Development of Equations

The equation of motion of a single degree of freedom (dof) system is given by

$$\ddot{X} + 2\xi_0 \omega_0 \dot{X} + \omega_0^2 X = -\ddot{u}_g$$

where:

X is the relative displacement with respect to the base,

ξ_0 is the damping ratio,

ω_0 is the natural frequency, and

$\ddot{u}_g$ is the base acceleration.

The transfer function of this system, which relates the Fourier transform of the input acceleration with the Fourier transform of the relative displacement is given by the expression

$$H(\omega) = \frac{1}{\omega_0^2 - \omega^2 + 2 i \omega_0 \omega \xi_0}$$

The power spectral density of the relative displacement of the single dof can be expressed in terms of the transfer function defined above and the power spectral density of the input acceleration as:

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$$S_d(\omega) = H(\omega)\bar{H}(\omega)\, S_a(\omega) = H^2(\omega)\, S_a(\omega)$$

where

$S_d(\omega)$ power spectral density of relative displacement

$\bar{H}(\omega)$ complex conjugate of $H(\omega)$

$S_a(\omega)$ power spectral density of input acceleration

Writing again the above equation, we have

$$S_d(\omega) = \frac{1}{(\omega_0^2-\omega^2)^2 + 4\xi_0^2\omega_0^2\omega^2}\, S_a(\omega) \qquad [1]$$

To generate the response spectra, we have to express the maximum response in terms of the power spectral density of the response. Using random vibration theory, the mean of the maximum response will be calculated.

The following basic relationships are needed

- Moments of the response

$$\lambda_m = \int_0^\infty \omega^m S_d(\omega)\, d\omega \qquad m = 0, 1, \ldots \qquad [1]$$

- Variance of the response

$$\sigma^2 = \lambda_0 \qquad [1]$$

- Mean of the maximum peak response

$$R(\omega_0, \xi_0) = p\sqrt{\lambda_0} \qquad [2]$$

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The peak factor, p, is defined in two ways. SPECGEN offers the choice of either peak factor.

1) Der Kiureghian [1] (Variable NPF = 1)

$$p = \sqrt{2\ln(\nu_e T)} + \frac{0.5772}{\sqrt{2\ln(\nu_e T)}}$$

where

$$\nu_e T = \begin{cases} \max(2.1,\ 2\delta\nu T) & 0 < \delta \le 0.1 \\ \max(2.1,\ (1.63\delta^{0.45} - 0.38)\nu T) & 0.1 < \delta \le 0.69 \\ \max(2.1,\ \nu T) & 0.69 < \delta \le 1.0 \end{cases}$$

T is the duration of the strong motion (sec.)

$$\delta = (1 - \lambda_1^2/\lambda_0\lambda_2)^{1/2}$$

$$\nu = \sqrt{\lambda_2/\lambda_0}\,/\,\pi$$

A lower bound of 2.1 is imposed on $\nu_e T$.

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2) Vanmarcke [2] (Variable NPF = 2)

$$p = \sqrt{2\ln\left[2n\left(1 - \exp\left(-\delta^{1.2}\sqrt{\pi\ln(2n)}\right)\right)\right]}$$

where

$$n = (\nu T/2)(-\ln(\hat{p}))^{-1}$$

$\hat{p}$ is the probability that the mean of the maximum peak response, $R(\omega_o, \zeta_o)$, will not be exceeded in duration T. SPECGEN uses a value of 0.5 for the probability.

To transform response spectra into power spectral density function and vise versa, it will be considered that the mean of the maximum peak response corresponds to the displacement spectrum ordinate at frequency ω_o and for damping ratio ζ_o.

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Evaluation of Moments λ_m

Exact Solution

$$\lambda_m = \int_0^\infty \omega^m S_d(\omega)\, d\omega$$

Introducing the expression for $S_d(\omega)$

$$\lambda_m = \int_0^\infty \frac{\omega^m}{(\omega_0^2-\omega^2)^2 + 4\xi_0^2\omega_0^2\omega^2} S_a(\omega)\, d\omega$$

To simplify the calculation of λ_m, let's assume that $S_a(\omega)$ is a linear piecewise function, so, between any two consecutive frequency points:

$$S_a(\omega) = \frac{S_a(\omega_{i+1}) - S_a(\omega_i)}{\omega_{i+1} - \omega_i} (\omega - \omega_i) + S_a(\omega_i)$$

$$S_a(\omega) = C_1 \omega + C_2$$

where $C_1 = \dfrac{S_a(\omega_{i+1}) - S_a(\omega_i)}{\omega_{i+1} - \omega_i}$

$$C_2 = \frac{\omega_{i+1} S_a(\omega_i) - \omega_i S_a(\omega_{i+1})}{\omega_{i+1} - \omega_i}$$

Then, the integral I_i between ω_i and ω_{i+1} is

$$I_i = \int_{\omega_i}^{\omega_{i+1}} \frac{C_1 \omega^{m+1}}{(\omega_0^2-\omega^2)^2 + 4\xi_0^2\omega_0^2\omega^2} d\omega + \int^{\omega_{i+1}} \frac{C_2 \omega^m}{(\omega_0^2-\omega^2)^2 + 4\xi_0^2\omega_0^2\omega^2} d\omega$$

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Then, for a curve defined between ω_1 and ω_N, λ_m will be calculated as

$$\lambda_m = I_0 + \sum_{i=1}^{N-1} I_i + I_\infty$$

where:

$$I_0 = \int_0^{\omega_1} H^2(\omega) Sa(\omega)\, \omega^m \, d\omega \quad \text{and}$$

$$I_\infty = \int_{\omega_N}^{\infty} H^2(\omega) Sa(\omega)\, \omega^m \, d\omega$$

Between 0 and ω_1, $Sa(\omega)$ will be assumed to be

$$Sa(\omega) = \left(\frac{\omega}{\omega_1}\right)^4 Sa(\omega_1) \qquad \omega = 0 \text{ to } \omega = \omega_1$$

Between ω_N and ∞, $Sa(\omega)$ will be assumed to be

$$Sa(\omega) = \left(\frac{\omega_N}{\omega}\right)^2 Sa(\omega_N) \qquad \omega = \omega_N \text{ to } \omega = \infty$$

Calculation of expressions for I_i, I_0, and I_∞.

First a recurrence formula for I_i will be developed:

The integral

$$\dot{K}_m = \int \frac{\omega^m}{(\omega_0^2 - \omega^2)^2 + 4\xi_0^2 \omega_0^2 \omega^2}\, d\omega \quad \text{can be written as:}$$

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$$K_m = \int \frac{\omega^m}{D} d\omega$$

doing

$$\frac{\omega^m}{D} = A\omega^{m-4} + B\frac{\omega^{m-2}}{D} + C\frac{\omega^{m-4}}{D} = \frac{AD\omega^{m-4} + B\omega^{m-2} + C\omega^{m-4}}{D}$$

$$D\omega^{m-4} = (\omega_0^4 + \omega^4 - 2\omega_0^2\omega^2 + 4\xi_0^2\omega_0^2\omega^2)\omega^{m-4}$$

$$D\omega^{m-4} = \omega^m + \omega_0^4\omega^{m-4} - 2\omega_0^2\omega^{m-2} + 4\xi_0^2\omega_0^2\omega^{m-2}$$

Then:

$$\omega^m = A\omega^m + A\omega_0^4\omega^{m-4} - A2\omega_0^2\omega^{m-2} + A4\xi_0^2\omega_0^2\omega^{m-2} +$$
$$B\omega^{m-2} + C\omega^{m-4}$$

$A = 1$

$-2\omega_0^2 + 4\xi_0^2\omega_0^2 + B = 0 \Rightarrow B = 2\omega_0^2(1-2\xi_0^2)$

$\omega_0^4 + C = 0 \Rightarrow C = -\omega_0^4$

Then

$$K_m = \frac{\omega^{m-3}}{m-3} + 2\omega_0^2(1-2\xi_0^2)K_{m-2} - \omega_0^4 K_{m-4} \qquad m \geq 4$$

~~For~~ I_i we need the following integrals

λ_0 : K_1 and K_0

λ_1 : K_2 and K_1

λ_2 : K_3 and K_2

For I_0 we need the following integrals

$\lambda_0 : K_4$

$\lambda_1 : K_5$

$\lambda_2 : K_6$

For I_∞ we need the following integrals

$\lambda_0 : K_{-2}$

$\lambda_1 : K_{-1}$

$\lambda_2 : K_0$

From [3] and [4]

$$K_0 = \frac{1}{4\omega_0^3}\left\{\frac{1}{2\sqrt{1-\xi_0^2}}\left[\ln\left(\omega^2+2\sqrt{1-\xi_0^2}\,\omega_0\omega+\omega_0^2\right) - \ln\left(\omega^2-2\sqrt{1-\xi_0^2}\,\omega_0\omega+\omega_0^2\right)\right] + \frac{1}{\xi_0}\left[\tan^{-1}\frac{\omega-\sqrt{1-\xi_0^2}\,\omega_0}{\xi_0\omega_0} + \tan^{-1}\frac{\omega+\sqrt{1-\xi_0^2}\,\omega_0}{\xi_0\omega_0}\right]\right\}$$

$$K_1 = \frac{1}{4\xi_0\sqrt{1-\xi_0^2}\,\omega_0^2}\ \tan^{-1}\frac{\omega^2-(1-2\xi_0^2)\omega_0^2}{2\xi_0\sqrt{1-\xi_0^2}\,\omega_0^2}$$

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$$K_2 = \frac{1}{8\sqrt{1-\xi_0^2}\,\omega_0}\left\{ \ln\left(\omega^2 - 2\sqrt{1-\xi_0^2}\,\omega_0\omega + \omega_0^2\right) - \ln\left(\omega^2 + 2\sqrt{1-\xi_0^2}\,\omega_0\omega + \omega_0^2\right)\right\} +$$

$$\frac{1}{4\xi_0\omega_0}\left\{ \tan^{-1}\frac{\omega - \sqrt{1-\xi_0^2}\,\omega_0}{\xi_0\omega_0} + \tan^{-1}\frac{\omega + \sqrt{1-\xi_0^2}\,\omega_0}{\xi_0\omega_0}\right\}$$

$$K_3 = \frac{1}{4}\ln\left[(\omega^2-\omega_0^2)^2 + 4\xi_0^2\omega^2\omega_0^2\right] +$$

$$\frac{1-2\xi_0^2}{4\xi_0\sqrt{1-\xi_0^2}}\tan^{-1}\frac{\omega^2 - (1-2\xi_0^2)\omega_0^2}{2\xi_0\sqrt{1-\xi_0^2}\,\omega_0^2}$$

$$K_{-1} = \frac{1}{4\omega_0^4}\left\{ \ln\omega^4 - \ln\left[(\omega^2-\omega_0^2)^2 + 4\xi_0^2\omega^2\omega_0^2\right] + \right.$$

$$\left. \frac{1-2\xi_0^2}{\xi_0\sqrt{1-\xi_0^2}}\tan^{-1}\frac{\omega^2 - (1-2\xi_0^2)\omega_0^2}{2\xi_0\sqrt{1-\xi_0^2}\,\omega_0^2}\right\}$$

$$K_{-2} = -\frac{1}{\omega_0^4\omega} - \frac{3-4\xi_0^2}{8\sqrt{1-\xi_0^2}\,\omega_0^5}\left\{ \ln\left(\omega^2 - 2\sqrt{1-\xi_0^2}\,\omega_0\omega + \omega_0^2\right) - \ln\left(\omega^2 + 2\sqrt{1-\xi_0^2}\,\omega_0\omega + \omega_0^2\right)\right\} +$$

$$\frac{1-4\xi_0^2}{4\xi_0\omega_0^5}\left\{ \tan^{-1}\frac{\omega - \sqrt{1-\xi_0^2}\,\omega_0}{\xi_0\omega_0} + \tan^{-1}\frac{\omega + \sqrt{1-\xi_0^2}\,\omega_0}{\xi_0\omega_0}\right\}$$

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Integrals for λ_0

$$I_0 = \frac{Sa(\omega_1)}{\omega_1^4}\left[K_4(\omega_1) - K_4(0) \right]$$

$$K_4(0) = 2\omega_0^2(1-2\xi_0^2)K_2(0) - \omega_0^4 K_0(0)$$

but $K_2(0) = 0$ and $K_0(0) = 0$, then

$$I_0 = \frac{Sa(\omega_1)}{\omega_1^4} K_4(\omega_1)$$

$$I_0 = \frac{Sa(\omega_1)}{\omega_1^4}\left\{ \omega_1 + 2\omega_0^2(1-2\xi_0^2)K_2(\omega_1) - \omega_0^4 K_0(\omega_1) \right\}$$

$$I_\infty = Sa(\omega_N)\,\omega_N^2 \left[K_{-2}(\infty) - K_{-2}(\omega_N) \right]$$

$$K_{-2}(\infty) = \frac{1-4\xi_0^2}{4\xi_0\omega_0^5}\pi$$

$$I_\infty = Sa(\omega_N)\,\omega_N^2 \left\{ \frac{1-4\xi_0^2}{4\xi_0\omega_0^5}\pi - K_{-2}(\omega_N) \right\}$$

$$I_i = C_1\left\{ K_1(\omega_{i+1}) - K_1(\omega_i) \right\} + C_2\left\{ K_0(\omega_{i+1}) - K_0(\omega_i) \right\}$$

$$= Sa(\omega_i)\left\{ -\frac{1}{\omega_{i+1}-\omega_i}\left(K_1(\omega_{i+1}) - K_1(\omega_i)\right) + \frac{\omega_{i+1}}{\omega_{i+1}-\omega_i}\left(K_0(\omega_{i+1}) - K_0(\omega_i)\right) \right\}$$

$$+ Sa(\omega_{i+1})\left\{ \frac{1}{\omega_{i+1}-\omega_i}\left(K_1(\omega_{i+1}) - K_1(\omega_i)\right) - \frac{\omega_i}{\omega_{i+1}-\omega_i}\left(K_0(\omega_{i+1}) - K_0(\omega_i)\right) \right\}$$

Then, λ_0 can be expressed as

$$\lambda_0(\omega_0, \xi_0) = \alpha_1 Sa(\omega_1) + \alpha_2 Sa(\omega_1) + \cdots + \alpha_N Sa(\omega_N)$$

where

$$\alpha_1 = \frac{1}{\omega_1^4}\left\{\omega_1 + 2\omega_0^2(1-2\xi_0^2) K_2(\omega_1) - \omega_0^4 K_0(\omega_1)\right\} -$$

$$\frac{1}{\omega_2 - \omega_1}\left\{K_1(\omega_2) - K_1(\omega_1)\right\} + \frac{\omega_2}{\omega_2 - \omega_1}\left\{K_0(\omega_2) - K_0(\omega_1)\right\}$$

$$\alpha_i = \frac{1}{\omega_i - \omega_{i-1}}\left(K_1(\omega_i) - K_1(\omega_{i-1})\right) - \frac{\omega_{i-1}}{\omega_i - \omega_{i-1}}\left(K_0(\omega_i) - K_0(\omega_{i-1})\right) -$$

$$\frac{1}{\omega_{i+1} - \omega_i}\left(K_1(\omega_{i+1}) - K_1(\omega_i)\right) + \frac{\omega_{i+1}}{\omega_{i+1} - \omega_i}\left(K_0(\omega_{i+1}) - K_0(\omega_i)\right)$$

for $i \geq 2$

$$\alpha_N = \frac{1}{\omega_N - \omega_{N-1}}\left(K_1(\omega_N) - K_1(\omega_{N-1})\right) - \frac{\omega_{N-1}}{\omega_N - \omega_{N-1}}\left(K_0(\omega_N) - K_0(\omega_{N-1})\right) +$$

$$\omega_N^2\left\{\pi \frac{1-4\xi_0^2}{4\xi_0 \omega_0^5} - K_{-2}(\omega_N)\right\}$$

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Integrals for λ_1

$$I_0 = \frac{S_a(\omega_1)}{\omega_1^4}\left[K_5(\omega_1) - K_5(0)\right]$$

$$K_5(0) = 2\omega_0^2(1-2\xi_0^2)K_3(0) - \omega_0^4 K_1(0)$$

$K_3(0) \neq 0$ and $K_1(0) \neq 0$

$$K_5(\omega_1) = \frac{\omega_1^2}{2} + 2\omega_0^2(1-2\xi_0^2)K_3(\omega_1) - \omega_0^4 K_1(\omega_1)$$

$$I_0 = S_a(\omega_1)\left\{\frac{1}{2\omega_1^2} + \frac{2\omega_0^2}{\omega_1^4}(1-2\xi_0^2)K_3(\omega_1) - \frac{\omega_0^4}{\omega_1^4}K_1(\omega_1) - \frac{2\omega_0^2}{\omega_1^4}(1-2\xi_0^2)K_3(0) + \frac{\omega_0^4}{\omega_1^4}K_1(0)\right\}$$

$$I_\infty = S_a(\omega_N)\,\omega_N^2\left\{K_{-1}(\infty) - K_{-1}(\omega_N)\right\}$$

$$K_{-1}(\infty) = \frac{1}{4\omega_0^4}\,\frac{1-2\xi_0^2}{\xi_0\sqrt{1-\xi_0^2}}\,\frac{\pi}{2} = \frac{\pi}{8\omega_0^4}\,\frac{1-2\xi_0^2}{\xi_0\sqrt{1-\xi_0^2}}$$

$$I_i = C_1\left\{K_2(\omega_{i+1}) - K_2(\omega_i)\right\} + C_2\left\{K_1(\omega_{i+1}) - K_1(\omega_i)\right\}$$

$$= S_a(\omega_i)\left\{-\frac{1}{\omega_{i+1}-\omega_i}\left(K_2(\omega_{i+1}) - K_2(\omega_i)\right) + \frac{\omega_{i+1}}{\omega_{i+1}-\omega_i}\left(K_1(\omega_{i+1}) - K_1(\omega_i)\right)\right\}$$

$$+ S_a(\omega_{i+1})\left\{\frac{1}{\omega_{i+1}-\omega_i}\left(K_2(\omega_{i+1}) - K_2(\omega_i)\right) - \frac{\omega_i}{\omega_{i+1}-\omega_i}\left(K_1(\omega_{i+1}) - K_1(\omega_i)\right)\right\}$$

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The moment λ_1 can be expressed by

$$\lambda_1(\omega_0, \xi_0) = \beta_1 Sa(\omega_1) + \beta_2 Sa(\omega_2) + \cdots + \beta_N Sa(\omega_N)$$

where

$$\beta_1 = \frac{1}{2\omega_1^2} + \frac{2\omega_0^2}{\omega_1^4}(1-2\xi_0^2)k_2(\omega_1) - \frac{\omega_0^4}{\omega_1^4}k_1(\omega_1) - \frac{2\omega_0^2}{\omega_1^4}(1-2\xi_0^2)k_3(0) +$$

$$\frac{\omega_0^4}{\omega_1^4}k_1(0) - \frac{1}{\omega_2-\omega_1}\left(k_2(\omega_2)-k_2(\omega_1)\right) + \frac{\omega_2}{\omega_2-\omega_1}\left(k_1(\omega_2)-k_1(\omega_1)\right)$$

$$\beta_i = \frac{1}{\omega_i-\omega_{i-1}}\left(k_2(\omega_i)-k_2(\omega_{i-1})\right) - \frac{\omega_{i-1}}{\omega_i-\omega_{i-1}}\left(k_1(\omega_i)-k_1(\omega_{i-1})\right) -$$

$$\frac{1}{\omega_{i+1}-\omega_i}\left(k_2(\omega_{i+1})-k_2(\omega_i)\right) + \frac{\omega_{i+1}}{\omega_{i+1}-\omega_i}\left(k_1(\omega_{i+1})-k_1(\omega_i)\right)$$

$$\beta_N = \frac{1}{\omega_N-\omega_{N-1}}\left(k_2(\omega_N)-k_2(\omega_{N-1})\right) - \frac{\omega_{N-1}}{\omega_N-\omega_{N-1}}\left(k_1(\omega_N)-k_1(\omega_{N-1})\right) +$$

$$\omega_A^2\left\{\frac{\pi}{8\omega_0^2}\frac{1-2\xi_0^2}{\xi_0\sqrt{1-\xi_0^2}} - k_{-1}(\omega_N)\right\}$$

Integrals for λ_2

$$I_0 = \frac{Sa(\omega_1)}{\omega_1^4}\left(K_6(\omega_1) - K_6(0)\right)$$

$$K_6(0) = 2\omega_0^2(1-2\xi_0^2)\,K_4(0) - \omega_0^2\,K_2(0) = 0$$

$$I_0 = \frac{Sa(\omega_1)}{\omega_1^4}\,K_6(\omega_1)$$

$$I_\infty = \omega_N^2\,Sa(\omega_N)\left\{K_0(\infty) - K_0(\omega_N)\right\}$$

$$K_0(\infty) = \frac{1}{4\omega_0^3}\,\frac{1}{\xi_0}\,\pi = \frac{\pi}{4\xi_0\omega_0^3}$$

$$I_\infty = Sa(\omega_N)\,\omega_N^2\left\{\frac{\pi}{4\xi_0\omega_0^3} - K_0(\omega_N)\right\}$$

$$I_i = C_1\left\{K_3(\omega_{i+1}) - K_3(\omega_i)\right\} + C_2\left\{K_2(\omega_{i+1}) - K_2(\omega_i)\right\}$$

$$I_i = Sa(\omega_i)\left\{-\frac{1}{\omega_{i+1}-\omega_i}\left(K_3(\omega_{i+1}) - K_3(\omega_i)\right) + \frac{\omega_{i+1}}{\omega_{i+1}-\omega_i}\left(K_2(\omega_{i+1}) - K_2(\omega_i)\right)\right\}$$

$$+\,Sa(\omega_{i+1})\left\{\frac{1}{\omega_{i+1}-\omega_i}\left(K_3(\omega_{i+1}) - K_3(\omega_i)\right) - \frac{\omega_i}{\omega_{i+1}-\omega_i}\left(K_2(\omega_{i+1}) - K_2(\omega_i)\right)\right\}$$

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The moment λ_2 can be expressed by

$$\lambda_2(\omega_0, \xi_0) = \beta_1 S_a(\omega_1) + \beta_2 S_a(\omega_2) + \cdots + \beta_N S_a(\omega_N)$$

where

$$\beta_1 = \frac{K_2(\omega_1)}{\omega_1^0} - \frac{1}{\omega_2 - \omega_1}\left(K_3(\omega_2) - K_3(\omega_1)\right) + \frac{\omega_2}{\omega_2 - \omega_1}\left(K_2(\omega_2) - K_2(\omega_1)\right)$$

$$\beta_i = \frac{1}{\omega_i - \omega_{i-1}}\left(K_3(\omega_i) - K_3(\omega_{i-1})\right) - \frac{\omega_{i-1}}{\omega_i - \omega_{i-1}}\left(K_2(\omega_i) - K_2(\omega_{i-1})\right) -$$

$$\frac{1}{\omega_{i+1} - \omega_i}\left(K_3(\omega_{i+1}) - K_3(\omega_i)\right) + \frac{\omega_{i+1}}{\omega_{i+1} - \omega_i}\left(K_2(\omega_{i+1}) - K_2(\omega_i)\right)$$

$$\beta_N = \frac{\omega_N^2 \pi}{4 \xi_0 \omega_0^3} - \omega_N^2 K_0(\omega_N) + \frac{1}{\omega_N - \omega_{N-1}}\left(K_3(\omega_N) - K_3(\omega_{N-1})\right) -$$

$$\frac{\omega_{N-1}}{\omega_N - \omega_{N-1}}\left(K_2(\omega_N) - K_2(\omega_{N-1})\right)$$

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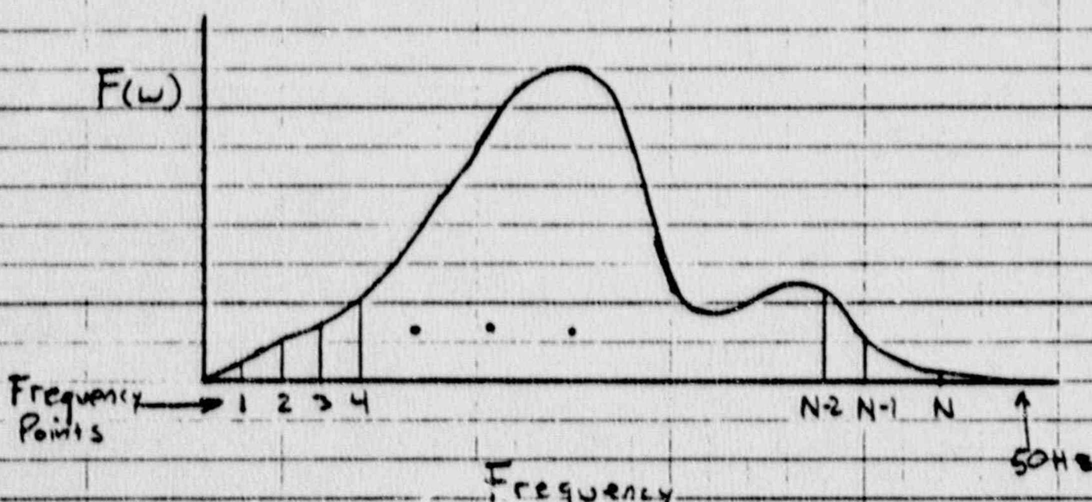
Approximate Solution

Alternatively, numerical values for the λ_m integrals can be calculated using numerical integration. A function to be integrated is shown schematically with N integration points in the figure below (N corresponds to the number of output frequency points (NOF) in SPECGEN.).



The integrals needed by SPECGEN are

$$\lambda_m = \int_0^\infty F(\omega)\, d\omega \qquad m = 1, 2, 3$$

where

$$F(\omega) = \omega^m H^2(\omega) S_a(\omega)$$

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The integrals can also be written in the form

$$\lambda_m = I_0 + \sum_{i=1}^{N-1} I_i + I_\infty$$

Using the Trapezoidal Rule

$$\sum_{i=1}^{N-1} I_i = \sum_{i=1}^{N-1} \left(\frac{F(\omega_i) + F(\omega_{i+1})}{2} \right)(\omega_{i+1} - \omega_i)$$

Substituting $F(\omega) = \omega^m H^2(\omega) S_a(\omega)$

$$\sum_{i=1}^{N-1} I_i = \sum_{i=1}^{N-1} \tfrac{1}{2}\left(\omega_i^m H^2(\omega_i) S_a(\omega_i) + \omega_{i+1}^m H^2(\omega_{i+1}) S_a(\omega_{i+1}) \right)(\omega_{i+1} - \omega_i)$$

Between 0 and ω_1, $F(\omega)$ is assumed to be linear from a value of $F(0) = 0$ to $F(\omega_1) = F(\omega_1)$.

$$I_0 = \frac{F(\omega_1)}{2}\omega_1 = \tfrac{1}{2}\omega_1^{m+1} H^2(\omega_1) S_a(\omega_1)$$

Between ω_N and 50Hz, $F(\omega)$ is assumed to be linear from a value of $F(\omega_N) = F(\omega_N)$ to $F(50Hz) = 0$.

$$I_\infty = \frac{F(\omega_N)}{2}(50Hz \cdot 2\pi - \omega_N) = \tfrac{1}{2}\omega_N^m H^2(\omega_N) S_a(\omega_N)(100\pi - \omega_N)$$

Then, the λ_m integrals have the form

$$\lambda_m = \tfrac{1}{2}\omega_1^{m+1} H^2(\omega_1) S_a(\omega_1) + \sum_{i=1}^{N-1}\left[\tfrac{1}{2}\left(\omega_i^m H^2(\omega_i) S_a(\omega_i) + \omega_{i+1}^m H^2(\omega_{i+1}) S_a(\omega_{i+1})\right)(\omega_{i+1} - \omega_i)\right] + \tfrac{1}{2}\left(\omega_N^m H^2(\omega_N) S_a(\omega_N)\right)(100\pi - \omega_N)$$

The λ_0 integral has the form

$$\lambda_0 = \frac{1}{2}\omega_1 H^2(\omega_1) S_a(\omega_1) + \sum_{i=1}^{N-1} \frac{1}{2}\left[H^2(\omega_i) S_a(\omega_i) + H^2(\omega_{i+1}) S_a(\omega_{i+1})\right](\omega_{i+1}-\omega_i)$$

$$+ \frac{1}{2}\left(H^2(\omega_N) S_a(\omega_N)\right)(100\pi - \omega_N)$$

and can be expressed as

$$\lambda_0 = \alpha_1 S_a(\omega_1) + \alpha_2 S_a(\omega_2) + \cdots + \alpha_i S_a(\omega_i) + \cdots + \alpha_N S_a(\omega_N)$$

where

$$\alpha_1 = \frac{1}{2} H^2(\omega_1)\,\omega_2$$

$$\alpha_2 = \frac{1}{2} H^2(\omega_2)(\omega_3 - \omega_1)$$

$$\alpha_i = \frac{1}{2} H^2(\omega_i)(\omega_{i+1} - \omega_{i-1}) \qquad i = 2 \text{ to } i = N-1$$

$$\alpha_N = \frac{1}{2} H^2(\omega_N)(100\pi - \omega_{N-1})$$

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The λ_1 integral has the form

$$\lambda_1 = \frac{1}{2} W_1^2 H^2(\omega_1) S_0(\omega_1) + \sum_{i=1}^{N-1} \frac{1}{2}\left[\omega_i H^2(\omega_i) S_0(\omega_i) + \omega_{i+1} H^2(\omega_{i+1}) S_0(\omega_{i+1})\right](\omega_{i+1} - \ldots$$

$$+ \frac{1}{2}\left(\omega_N H^2(\omega_N) S_0(\omega_N)\right)(100\pi - \omega_N)$$

and can be expressed as

$$\lambda_1 = \beta_1 S_0(\omega_1) + \beta_2 S_0(\omega_2) + \cdots + \beta_i S_0(\omega_i) + \cdots + \beta_N S_0(\omega_N)$$

where

$$\beta_1 = \frac{1}{2} H^2(\omega_1)\, \omega_1 \omega_2$$

$$\beta_2 = \frac{1}{2} H^2(\omega_2)\, \omega_2 (\omega_3 - \omega_1)$$

$\vdots$

$$\beta_i = \frac{1}{2} H^2(\omega_i)\, \omega_i (\omega_{i+1} - \omega_{i-1}) \qquad i = 2 \text{ to } i = N-1$$

$\vdots$

$$\beta_N = \frac{1}{2} H^2(\omega_N)\, \omega_N (100\pi - \omega_{N-1})$$

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The λ_2 integral has the form

$$\lambda_2 = \frac{1}{2} \omega_1^3 H^2(\omega_1) S_a(\omega_1) + \sum_{i=1}^{N-1} \frac{1}{2} \left[\omega_i^2 H^2(\omega_i) S_a(\omega_i) + \omega_{i+1}^2 H^2(\omega_{i+1}) S_a(\omega_{i+1}) \right] (\omega_{i+1} - \omega_i)$$

$$+ \frac{1}{2} \omega_N^2 H^2(\omega_N) S_a(\omega_N) (100\pi - \omega_N)$$

and can be expressed as

$$\lambda_2 = \gamma_1 S_a(\omega_1) + \gamma_2 S_a(\omega_2) + \cdots + \gamma_i S_a(\omega_i) + \cdots + \gamma_N S_a(\omega_N)$$

where

$$\gamma_1 = \frac{1}{2} H^2(\omega_1) \omega_1^2 \omega_2$$

$$\gamma_2 = \frac{1}{2} H^2(\omega_2) \omega_2^2 (\omega_3 - \omega_1)$$

⋮

$$\gamma_i = \frac{1}{2} H^2(\omega_i) \omega_i^2 (\omega_{i+1} - \omega_{i-1}) \qquad i = 2 \text{ to } i = N-1$$

⋮

$$\gamma_N = \frac{1}{2} H^2(\omega_N) \omega_N^2 (100\pi - \omega_{N-1})$$

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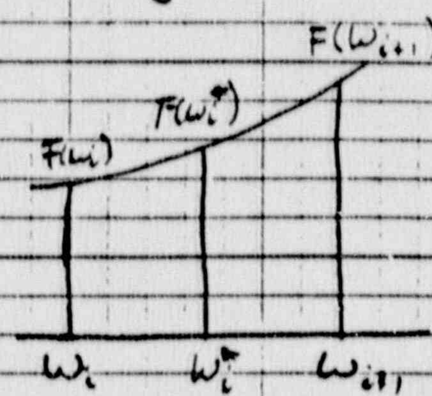
Refine the mesh by adding N-2 intermediate points.



Again we need the λ_m integrals

$$\lambda_m = I_0 + \sum_{i=1}^{N-1} I_i + I_\infty$$

for m = 0, 1, 2.

I_0 and I_∞ remain unchanged while I_i takes the form

$$\sum_{i=1}^{N-1} I_i = \sum_{i=1}^{N-1} \left[\tfrac{1}{2}\left(F(W_i) + F(W_i^*)\right)(W_i^* - W_i) + \tfrac{1}{2}\left(F(W_i^*) + F(W_{i+1})\right)(W_{i+1} - W_i^*) \right]$$

Substituting $W_i^* = \tfrac{1}{2}(W_{i+1} + W_i)$

$$\sum_{i=1}^{N-1} I_i = \sum_{i=1}^{N-1} \left[\tfrac{1}{4}(W_{i+1} - W_i)\left[F(W_i) + 2F(W_i^*) + F(W_{i+1}) \right] \right]$$

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Next, insert $F(\omega) = \omega^m H^2(\omega)\, S_a(\omega)$

$$\sum_{i=1}^{N-1} I_i = \sum_{i=1}^{N-1} \Big[\tfrac{1}{4}(\omega_{i+1} - \omega_i)\big[\omega_i^m H^2(\omega_i) S_a(\omega_i) + 2\,\omega_i^{*m} H^2(\omega_i^*) S_a(\omega_i^*) + \omega_{i+1}^m H^2(\omega_{i+1}) S_a(\omega_{i+1}) \big]\Big]$$

where

$$H(\omega_i^*) = H\left(\frac{\omega_{i+1} + \omega_i}{2}\right)$$

$$S_a(\omega_i^*) = \frac{S_a(\omega_i) + S_a(\omega_{i+1})}{2}$$

Substituting for $S_a(\omega_i^*)$

$$\sum_{i=1}^{N-1} I_i = \sum_{i=1}^{N-1} \Big[\tfrac{1}{4}(\omega_{i+1} - \omega_i)\big[\omega_i^m H^2(\omega_i) S_a(\omega_i) + \omega_i^{*m} H^2(\omega_i^*) \big(S_a(\omega_i) + S_a(\omega_{i+1})\big) + \omega_{i+1}^m H^2(\omega_{i+1}) S_a(\omega_{i+1}) \big]\Big]$$

Substituting for ω^* and simplifying

$$\sum_{i=1}^{N-1} I_i = \sum_{i=1}^{N-1} \tfrac{1}{4}(\omega_{i+1} - \omega_i)\Big[\Big(\omega_i^m H^2(\omega_i) + \big(\tfrac{1}{2}(\omega_{i+1} + \omega_i)\big)^m H^2(\omega_i^*)\Big) S_a(\omega_i) + \Big(\big(\tfrac{1}{2}(\omega_{i+1} + \omega_i)\big)^m H^2(\omega_i^*) + \omega_{i+1}^m H^2(\omega_{i+1})\Big) S_a(\omega_{i+1}) \Big]$$

The λ_m integrals have the form

$$\lambda_m = \tfrac{1}{2}\omega_1^{m+1} H^2(\omega_1) S_c(\omega_1) + \sum_{i=1}^{N-1} \tfrac{1}{4}(\omega_{i+1}-\omega_i)\Big[\big(\omega_i^m H^2(\omega_i) + \big(\tfrac{1}{2}(\omega_{i+1}+\omega_i)\big)^m H^2(\omega_i^*)\big) S_c(\omega_i) + \big(\tfrac{1}{2}(\omega_{i+1}+\omega_i)\big)^m H^2(\omega_i^*) + \omega_{i+1}^m H^2(\omega_{i+1})\big) S_c(\omega_{i+1})\Big] + \tfrac{1}{2}\big(\omega_N^m H^2(\omega_N) S_c(\omega_N)\big)(100\pi - \omega_N)$$

The λ_0 integral is written

$$\lambda_0 = \alpha_1 S_c(\omega_1) + \alpha_2 S_c(\omega_2) + \cdots + \alpha_i S_c(\omega_i) + \cdots + \alpha_N S_c(\omega_N)$$

where

$$\alpha_1 = \tfrac{1}{4}\left[(\omega_1+\omega_2) H^2(\omega_1) + (\omega_2-\omega_1) H^2(\omega_1^*)\right]$$

$$\alpha_2 = \tfrac{1}{4}\left[H^2(\omega_1^*)(\omega_2-\omega_1) + H^2(\omega_2)(\omega_3-\omega_1) + H^2(\omega_2^*)(\omega_3-\omega_2)\right]$$

$\vdots$

$$\alpha_i = \tfrac{1}{4}\left[H^2(\omega_{i-1}^*)(\omega_i-\omega_{i-1}) + H^2(\omega_i)(\omega_{i+1}-\omega_{i-1}) + H^2(\omega_i^*)(\omega_{i+1}-\omega_i)\right]$$

$\vdots$

$$\alpha_N = \tfrac{1}{4}\left[H^2(\omega_{N-1}^*)(\omega_N-\omega_{N-1}) + H^2(\omega_N)(200\pi - (\omega_{N-1}+\omega_N))\right]$$

The λ_1 integral is written

$$\lambda_1 = \beta_1 S_c(\omega_1) + \beta_2 S_c(\omega_2) + \cdots + \beta_i S_c(\omega_i) + \cdots + \beta_N S_c(\omega_N)$$

where

$$\beta_1 = \frac{1}{4}\left[\omega_1(\omega_1+\omega_2)H^2(\omega_1) + \frac{1}{2}(\omega_2-\omega_1)(\omega_2+\omega_1)H^2(\omega_1^*)\right]$$

$$\beta_2 = \frac{1}{4}\left[\frac{1}{2}(\omega_2-\omega_1)(\omega_2+\omega_1)H^2(\omega_1^*) + (\omega_3-\omega_1)\omega_2 H^2(\omega_2) + \frac{1}{2}(\omega_3-\omega_2)(\omega_3+\omega_2)H^2(\omega_2^*)\right]$$

⋮

$$\beta_i = \frac{1}{4}\left[\frac{1}{2}(\omega_i-\omega_{i-1})(\omega_i+\omega_{i-1})H^2(\omega_{i-1}^*) + (\omega_{i+1}-\omega_{i-1})\omega_i H^2(\omega_i) + \frac{1}{2}(\omega_{i+1}-\omega_i)(\omega_{i+1}+\omega_i)H^2(\omega_i^*)\right]$$

⋮

$$\beta_N = \frac{1}{4}\left[\frac{1}{2}(\omega_N-\omega_{N-1})(\omega_N+\omega_{N-1})H^2(\omega_{N-1}^*) + \omega_N(200\pi-\omega_N-\omega_{N-1})H^2(\omega_N)\right]$$

The λ_2 integral is written

$$\lambda_2 = \gamma_1 S_c(\omega_1) + \gamma_2 S_c(\omega_2) + \cdots + \gamma_i S_c(\omega_i) + \cdots + \gamma_N S_c(\omega_N)$$

where

$$\gamma_1 = \frac{1}{4}\left[\omega_1^2(\omega_1+\omega_2)H^2(\omega_1) + \frac{1}{4}(\omega_2-\omega_1)(\omega_2+\omega_1)^2 H^2(\omega_1^*)\right]$$

$$\gamma_2 = \frac{1}{4}\Big[\frac{1}{4}(\omega_2-\omega_1)(\omega_2+\omega_1)^2 H^2(\omega_1^*) + (\omega_3-\omega_1)\omega_2^2 H^2(\omega_2) + \frac{1}{4}(\omega_3-\omega_2)(\omega_3+\omega_2)^2 H^2(\omega_2^*)$$

⋮

$$\gamma_i = \frac{1}{4}\left[\frac{1}{4}(\omega_i-\omega_{i-1})(\omega_i+\omega_{i-1})^2 H^2(\omega_{i-1}^*) + (\omega_{i+1}-\omega_{i-1})\omega_i^2 H^2(\omega_i) + \frac{1}{4}(\omega_{i+1}-\omega_i)(\omega_{i+1}+\omega_i)^2 H^2(\omega_i^*)\right]$$

⋮

$$\gamma_N = \frac{1}{4}\left[\frac{1}{4}(\omega_N-\omega_{N-1})(\omega_N+\omega_{N-1})^2 H^2(\omega_{N-1}^*) + \omega_N^2(200\pi-\omega_N-\omega_{N-1})H^2(\omega_N)\right]$$

2 5 4

SPECGEN uses the numerical integration method with the refined mesh to evaluate the Am integrals. During the development of the program, it was demonstrated that the results obtained when using the numerical integration method are identical to those obtained when using the exact solution. The advantage of using the numerical integration method is that it requires much less CPU computer time.

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Evaluation of the power spectral density function from a response spectrum curve

Assume that $R(\omega, \xi_0)$ are the spectral values for a spectrum with ξ_0 damping ratio. The procedure to generate a power spectral density function compatible with R is as follows:

1- Assume a power spectral density function given by $\langle S_a(\omega_1), S_a(\omega_2), \ldots, S_a(\omega_N) \rangle = S_0(\omega)$

2- Calculate $\lambda_0(\omega_0, \xi_0)$ for $\omega_0 = \omega_1, \omega_2, \ldots, \omega_N$

$$\lambda_0(\omega_0, \xi_0) = \alpha_1 S_a(\omega_1) + \alpha_2 S_a(\omega_2) + \cdots + \alpha_N S_a(\omega_N)$$

3- Calculate $\lambda_1(\omega_0, \xi_0)$ and $\lambda_2(\omega_0, \xi_0)$ for $\omega_0 = \omega_1, \omega_2, \ldots, \omega_N$

4- Calculate the peak factor $p(\omega_0, \xi_0)$ for $\omega_0 = \omega_1, \omega_2, \ldots, \omega_N$

5- Calculate a compatible response spectrum as

$$\bar{R}(\omega_0, \xi_0) = p(\omega_0, \xi_0)\sqrt{\lambda_0(\omega_0, \xi_0)} \quad \text{for } \omega_0 = \omega_1, \omega_2, \ldots \omega_N$$

6- Calculate the error in the response spectrum as

$$e(\omega_0, \xi_0) = \frac{R(\omega_0, \xi_0)}{\bar{R}(\omega_0, \xi_0)} \quad \text{for } \omega_0 = \omega_1, \omega_2, \ldots, \omega_N$$

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7: Calculate a new spectral density function as

$$S_1(\omega_0, \xi_0) = e^2(\omega_0, \xi_0)\, S_0(\omega_0, \xi_0) \quad \text{for } \omega_0 = \omega_1, \omega_2, \ldots, \omega_N$$

8: Go back to step 2. The iterative process stops when the error is smaller than a specified tolerance

9: Once the power spectral density function compatible with the original response spectrum has been obtained, the response spectrum for any damping ξ_1 can be calculated as

$$R(\omega_0, \xi_1) = p(\omega_0, \xi_1)\sqrt{\lambda_0(\omega_0, \xi_1)} \quad \omega_0 = \omega_1, \omega_2, \ldots, \omega_N$$

The error e (and thus the specified tolerance) is a measure of the accuracy of the results obtained. Even if this error is measured against the input spectrum, this could be seen as an indicator of the errors in the extrapolated spectra.

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- Correction for Nonstationary Characteristics of Earthquakes (Variable-MODDAMP=1 implies correction)

The formulation used in the development of this methodology assumes that the earthquakes can be represented by stationary processes. However, for oscillators of very low frequencies, typical earthquakes will not produce a stationary state of oscillation. Following the recommendation of Rosenblueth and Elorduy [3], corrections to the oscillator damping of the form

$$\xi_e = \xi + \frac{2}{\omega \tau}$$

will appropriately account for the finite process. In the above formula

ξ_e is an equivalent damping

ξ is the damping of the oscillator

ω is the frequency of the oscillator and

τ is the duration of the strong motion.

The damping correction term has to be applied to all the expressions developed before.

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ATTACHMENT 6
COMPUTER PROGRAM SHAKE USER'S MANUAL

EARTHQUAKE ENGINEERING RESEARCH CENTER

SHAKE

A COMPUTER PROGRAM FOR EARTHQUAKE RESPONSE ANALYSIS OF HORIZONTALLY LAYERED SITES

by

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A Computer program distributed by
NISEE / Computer Applications

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1. INTRODUCTION

Several methods for evaluating the effect of local soil conditions on ground response during earthquakes are presently available. Most of these methods are based on the assumption that the main responses in a soil deposit are caused by the upward propagation of shear waves from the underlying rock formation. Analytical procedures based on this concept incorporating nonlinear soil behavior, have been shown to give results in good agreement with field observations in a number of cases. Accordingly they are finding increasing use in earthquake engineering for predicting responses within soil deposits and the characteristics of ground surface motions.

The analytical procedure generally invo[illegible] following steps:

1. Determine the characteristics of th[illegible] tions likely to develop in the rock formation underlying the si[illegible], and select an accelerogram with these characteristics for use in the analysis.

   The maximum acceleration, predominant period, and effective duration are the most important parameters of an earthquake motion. Empirical relationships between these parameters and the distance from the causative fault to the site have been established for different magnitude earthquakes (Gutenberg and Richter, 1956, Seed et al., 1969, Schnabel and Seed, 1972). A design motion with the desired characteristics can be selected from the strong motion accelerograms that have been recorded during previous earthquakes (Seed and Idriss, 1969) or from artificially generated accelerograms (Housner and Jennings, 1964).

2. Determine the dynamic properties of the soil deposit.
   Average relationships between the dynamic shear moduli and damping ratios of soils, as functions of shear strain and static properties, have been established for various soil types (Hardin and Drnevich, 1970, Seed and Idriss, 1970). Thus a relatively simple testing program to obtain the static properties for use in these relationships will often serve to establish the dynamic properties with a sufficient degree of accuracy. However more elaborate dynamic testing procedures are required for special problems and for cases involving soil types for which empirical relationships with static properties have not been established.
3. Compute the response of the soil deposit to the base-rock motions.
   A one-dimensional method of analysis can be used if the soil structure is essentially horizontal. Programs developed for performing this analysis are in general based on either the solution to the wave equation (Kanai, 1951; Matthiesen et al., 1964; Roesset and Whitman, 1969; Lysmer et al., 1971) or on a lumped mass simulation (Idriss and Seed, 1968). More irregular soil deposits may require a finite element analysis.

In the following sections the theory and use of a computer program based on the one-dimensional wave propagation method are described. The program can compute the responses for a design motion given anywhere in the system. Thus accelerograms obtained from instruments on soil deposits can be used to generate new rock motions which, in turn, can be used as design motion for other soil deposits, see Fig. 1 (Schnabel et al., 1971). The program also incorporates nonlinear soil behavior, the effect of the elasticity of the base rock and systems with variable damping.

2. THEORY

The theory considers the responses associated with vertical propagation of shear waves through the linear viscoelastic system shown in Fig. 2. The system consists of N horizontal layers which extend to infinity in the horizontal direction and has a halfspace as the bottom layer. Each layer is homogeneous and isotropic and is characterized by the thickness, h, mass density, ρ, shear modulus, G, and damping factor, β.

2.1 Propagation of harmonic shear waves in a one-dimensional system.

Vertical propagation of shear waves through the system shown in Fig. 2 will cause only horizontal displacements:

$$u = u(x,t) \tag{1}$$

which must satisfy the wave equation:

$$\rho \frac{\partial^2 u}{\partial t^2} = G \frac{\partial^2 u}{\partial x^2} + \eta \frac{\partial^3 u}{\partial x^2 \partial t} \tag{2}$$

Harmonic displacements with frequency ω can be written in the form:

$$u(x,t) = U(x) \cdot e^{i\omega t} \tag{3}$$

Substituting Eq. 3 into Eq. 2 results in an ordinary differential equation:

$$(G + i\omega\eta) \frac{d^2U}{dx^2} = \rho\omega^2 U \tag{4}$$

which has the general solution

$$U(x) = Ee^{ikx} + Fe^{-ikx} \tag{5}$$

in which

$$k^2 = \frac{\rho\omega^2}{G + i\omega\eta} = \frac{\rho\omega^2}{G^*} \tag{6}$$

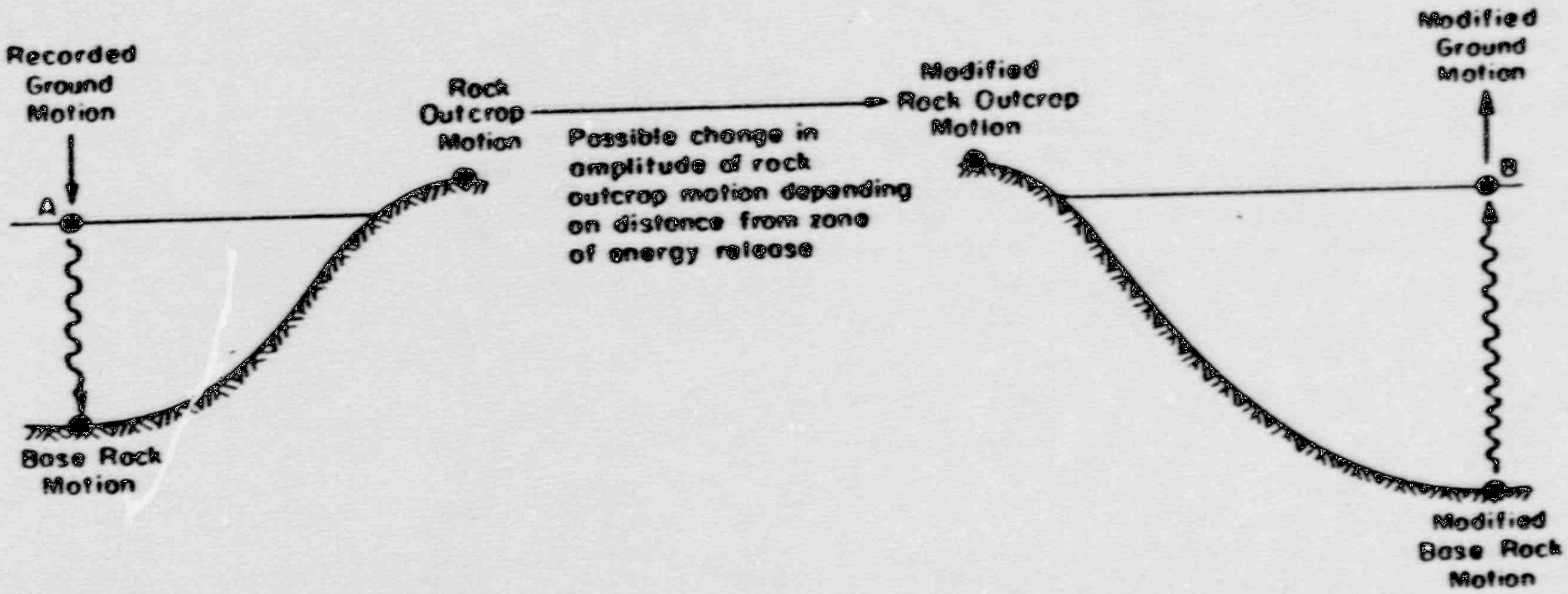


Fig. I SCHEMATIC REPRESENTATION OF PROCEDURE FOR COMPUTING EFFECTS OF LOCAL SOIL CONDITIONS ON GROUND MOTIONS

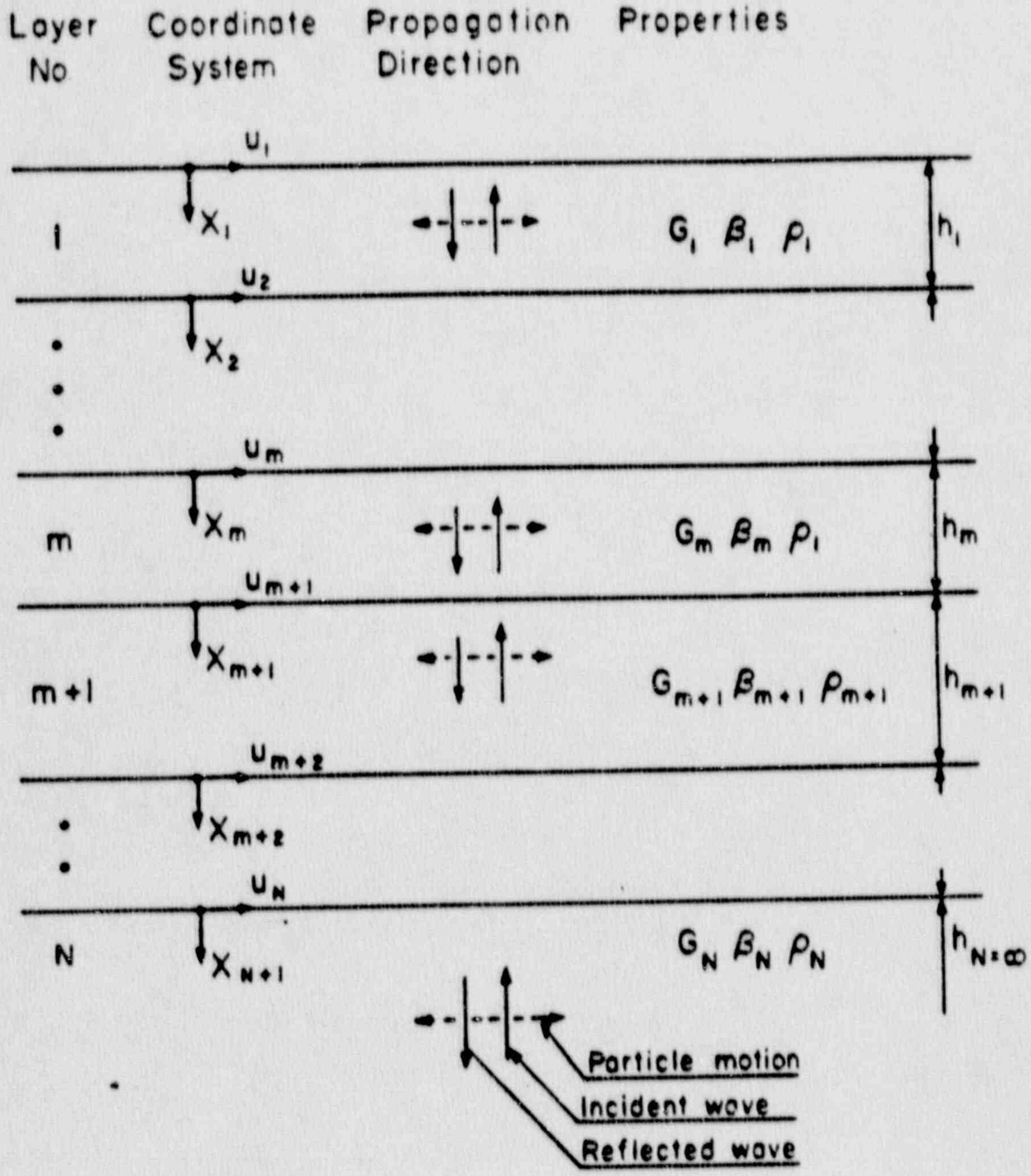


Fig. 2 ONE-DIMENSIONAL SYSTEM

where k is the complex wave number and G* is the complex shear modulus. The critical damping ratio, β, is related to the viscosity η by

$$\omega\eta = 2G\beta$$

Experiments on many soil materials indicate that G and β are nearly constant over the frequency range which is of main interest in the analysis. It is therefore convenient to express the complex shear modulus in terms of the critical damping ratio instead of the viscosity:

$$G^* = G + i\omega\eta = G(1+2i\beta) \tag{7}$$

where G* can be assumed to be independent of frequency.

Equations 3 and 5 give the solution to the wave equation for a harmonic motion of frequency ω:

$$u(x,t) = Ee^{i(kx+\omega t)} + Fe^{-i(kx-\omega t)} \tag{8}$$

where the first term represents the incident wave travelling in the negative x-direction (upwards) and the second term represents the reflected wave travelling in the positive x-direction (downwards).

Equation 8 is valid for each of the layers in Fig. 2. Introducing a local coordinate system X for each layer, the displacements at the top and bottom of layer m are:

$$u_m(X=0) = (E_m + F_m)e^{i\omega t} \tag{9}$$

$$u_m(X=h_m) = (E_m \cdot e^{ik_m h_m} + F_m e^{-ik_m h_m}) \cdot e^{i\omega t} \tag{10}$$

The shear stress on a horizontal plane is:

$$\tau(x,t) = G \cdot \frac{\partial u}{\partial x} + \eta \frac{\partial^2 u}{\partial x \partial t} = G^* \frac{\partial u}{\partial x} \tag{11}$$

or by Eq. 8:

$$\tau(x,t) = ikG^*(Ee^{ikx} - Fe^{-ikx})e^{i\omega t} \tag{12}$$

and the shear stresses at the top and bottom of layer m are respectively:

$$\tau_m(X=0) = ik_m G_m^* \,(E_m - F_m)e^{i\omega t} \tag{13}$$

$$\tau_m(X=h_m) = ik_m G_m^* \,(Ee^{ik_m h_m} - F_m e^{-ik_m h_m})e^{i\omega t} \tag{14}$$

Stresses and displacements must be continuous at all interfaces. Hence, by Eq. 9, 10, 13 and 14:

$$E_{m+1} + F_{m+1} = E_m e^{ik_m h_m} + F_m e^{-ik_m h_m} \tag{15}$$

$$E_{m+1} - F_{m+1} = \frac{k_m G_m^*}{k_{m+1} G_{m+1}^*} \,(E_m e^{ik_m h_m} - F_m e^{-ik_m h_m}) \tag{16}$$

Subtraction and addition of Eqs. 15 and 16 yield the following recursion formulas for the amplitudes, E_{m+1} and F_{m+1}, of the incident and reflected wave in layer m+1, expressed in terms of the amplitudes in layer m:

$$E_{m+1} = \tfrac{1}{2}E_m(1+\alpha_m)e^{ik_m h_m} + \tfrac{1}{2}F_m(1-\alpha_m)e^{-ik_m h_m} \tag{17}$$

$$F_{m+1} = \tfrac{1}{2}E_m(1-\alpha_m)e^{ik_m h_m} + \tfrac{1}{2}F_m(1+\alpha_m)e^{-ik_m h_m} \tag{18}$$

where α_m is the complex impedance ratio

$$\alpha_m = \frac{k_m G_m^*}{k_{m+1} G_{m+1}^*} = \left(\frac{\rho_m G_m^*}{\rho_{m+1} G_{m+1}^*}\right)^{1/2} \tag{19}$$

which again is independent of frequency.

At the free surface, the shear stresses must be zero. In addition, Eq. 12 with τ_1 and X_1 equal to zero gives $E_1 = F_1$ -i.e., the amplitudes of the incident and reflected waves are always equal at a free surface. Beginning with the surface layer, repeated use of the recursion formulas Eqs. 17 and 18 leads to the following relationships between the amplitudes in layer m and those in the surface layer:

$$E_m = e_m(\omega)\ E_1 \tag{20}$$

$$F_m = f_m(\omega)\ E_1 \tag{21}$$

The transfer functions e_m and f_m are simply the amplitudes for the case $E_1 = F_1 = 1$, and can be determined by substituting this condition into the above recursion formulas.

Other transfer functions are easily obtained from the e_m and f_m functions. The transfer function $A_{n,m}$ between the displacements at level n and m is defined by

$$A_{n,m}(\omega) = u_m/u_n$$

and by substituting Eqs. 9, 20 and 21:

$$A_{n,m}(\omega) = \frac{e_m(\omega) + f_m(\omega)}{e_n(\omega) + f_n(\omega)} \tag{22}$$

Based on these equations the transfer function $A(\omega)$ can be found between any two layers in the system. Hence, if the motion is known in any one layer in the system, the motion can be computed in any other layer.

The amplitudes, E and F can thus be computed for all layers in the system, and the strains and accelerations can be derived from the displacement function. Accelerations are expressed by the equation:

$$\ddot{u}(x,t) = \frac{\partial^2 u}{\partial t^2} = -\omega^2 (Ee^{i(kx+\omega t)} + Fe^{-i(kx-\omega t)}) \qquad (23)$$

and strains by:

$$\gamma = \frac{\partial u}{\partial x} = ik(Ee^{i(kx+\omega t)} - Fe^{-i(kx-\omega t)}) \qquad (24)$$

2.2 <u>Ratio between rock outcrop motions and base rock motions</u>.

If the amplitudes of the incident and reflected wave components, E_N and F_N, in the elastic halfspace, Fig. 3a, are known, the motions in the halfspace with the soil system removed, Fig. 3c, are easily computed. The shear stresses are zero at any free surface; thus $F_N = E_N$, and the incident wave is completely reflected with a resulting amplitude $2E_N$ at the free surface of the halfspace. The amplitude of the incident wave in the halfspace is independent of the properties of the system above it since the reflected wave is completely absorbed in the halfspace and does not contribute to the incident wave. The incident wave component, E_N, is therefore equal in all systems shown in Fig. 3.

The ratio between the base motion, u_N, and the motion, u'_N, at the free surface may be computed from the transfer function:

$$A'_N(\omega) = \frac{u_N}{u'_N} = \frac{e_N(\omega) + f_N(\omega)}{2e_N(\omega)} \qquad (25)$$

The transfer function between the motion at the surface of the deposit, u_1, and the motion at the free surface of the halfspace is:

$$A'_{N,1}(\omega) = \frac{1}{e_N(\omega)} \qquad (26)$$

If the halfspace is the rock formation underlying a soil deposit, Eq. 25 shows the ratio between the motion in the base rock and in the outcropping rock. The ratio between the amplitudes of the base rock motion

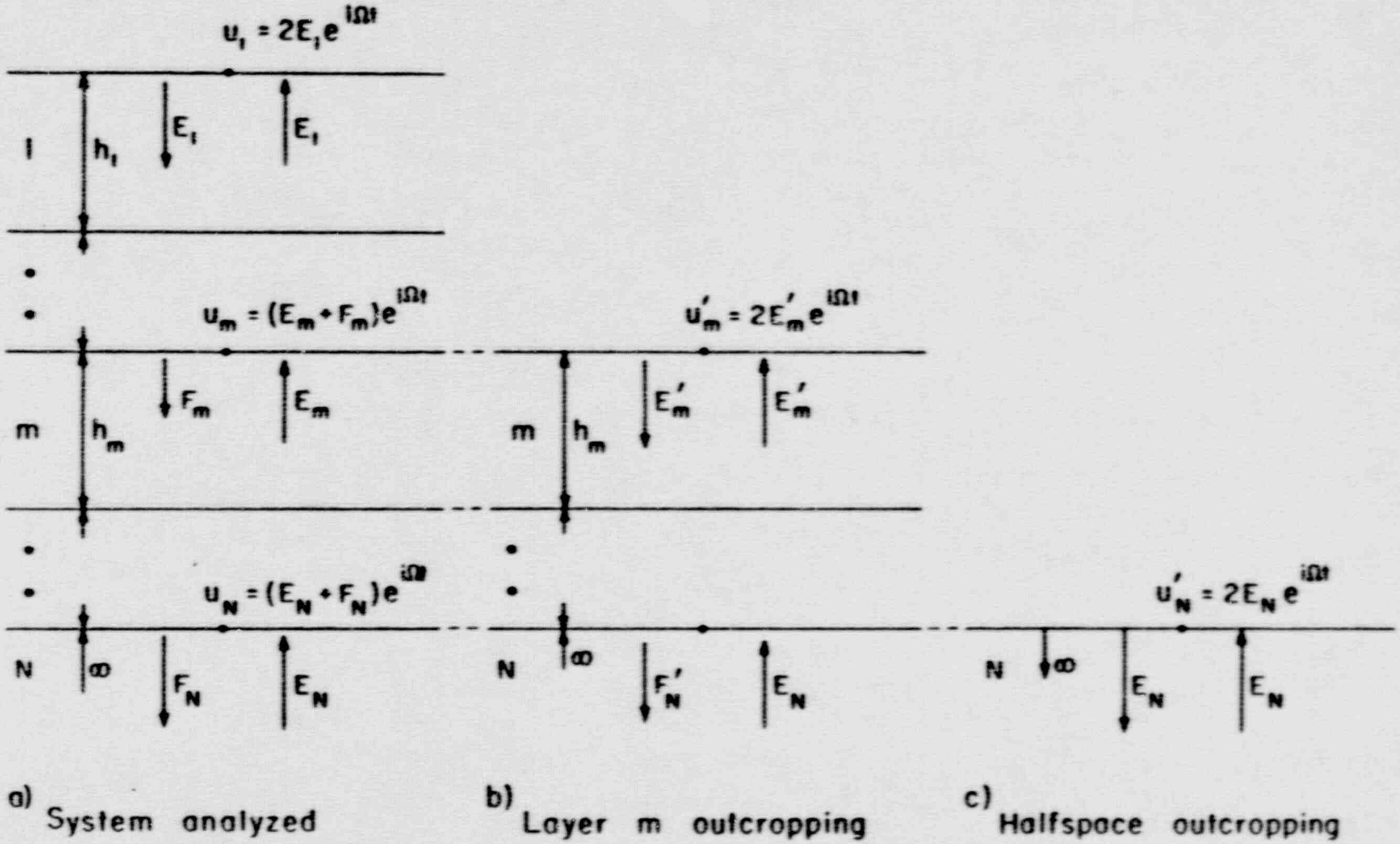
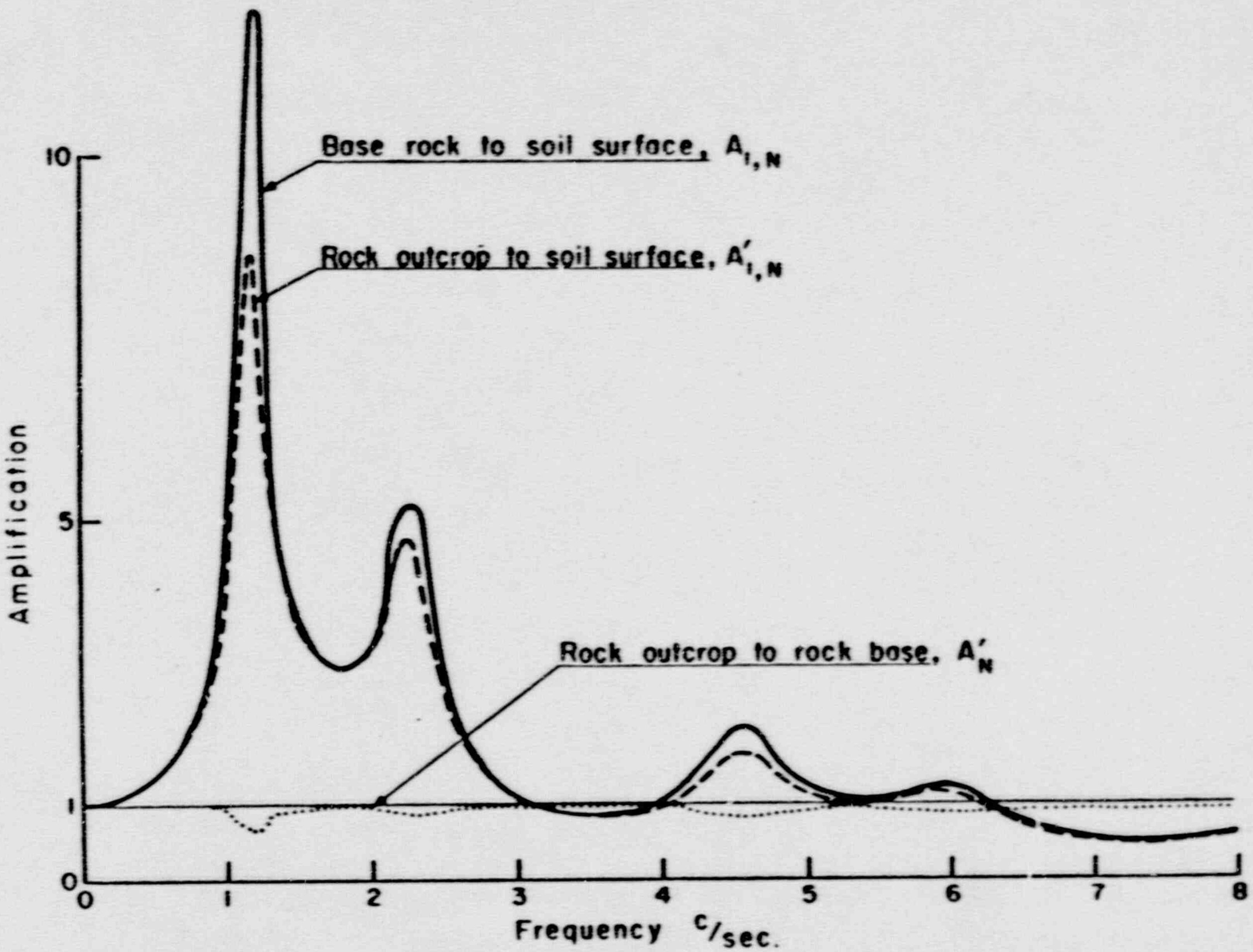


Fig 3 ONE-DIMENSIONAL SYSTEM WITH OUTCROPPING LAYERS

and the outcropping rock motion is always less than 1, with minimum values at the resonance frequencies of the deposit. Transfer functions for the deposit used in the example, (Sect. 6), are shown in Fig. 4. The amplitude of the base rock motion is only 65% of the amplitude of the rock outcrop motion at the fundamental frequency of the deposit. This difference is a function of the impedance ratio between the deposit and the rock and of the damping in the deposit.

The differences in the computed responses resulting from the use of a rigid base, relative to the use of an elastic base, depend also on which frequencies are dominant in the rock motion. Rock motions with frequency dominance near the resonant frequencies of the deposit will be considerably more affected than motions with frequency dominance between the resonance frequencies, see Fig. 4. The effect of the elasticity of the base rock is, therefore, not only a function of the impedance ratio between deposit and rock and of the damping in the deposit, but also of the frequency distribution of the energy in the rock motion relative to the resonance frequencies of the deposit.

An approximation for the free surface motion for one of the layers in the system, Fig. 3b, may be obtained in the same way as for the halfspace, provided the incident wave component in the outcropping layer and in the layer within the system are equal--i.e. $E_m = E_m'$. This is approximately the case when the properties of layer m and all layers below are equal in the two systems and when the impedance, $\rho_m V_m$, is of the same order of magnitude as for the halfspace. This is the case for example, in sedimentary rock layers overlying a crystalline rock base. For a more accuate solution, the motion in outcropping layers must be computed in a separate system from the motion in the halfspace.



Base rock to soil surface, $A_{1,N}$
Rock outcrop to soil surface, $A'_{1,N}$
Rock outcrop to rock base, A'_N
Amplification
10
5
1
0
0
1
2
3
4
5
6
7
8
Frequency c/sec.

2.3 Transient motions

The expressions developed above are valid for steady state harmonic motions. The theory can be extended to transient motions through the use of Fourier transformation.

A digitized seismogram with n equidistant acceleration values, $\ddot{u}_j(j\cdot\Delta t)$, $j = 0,\ldots,n-1$, can be represented by a finite sum of harmonic motions:

$$\ddot{u}(t) = \sum_{s=0}^{n/2} (a_s e^{i\omega_s t} + b_s e^{-i\omega_s t}) \tag{27}$$

where ω_s, $s=0,\ldots,n/2$ are the equidistant frequencies:

$$\omega_s = \frac{2\pi}{n\cdot\Delta t}\cdot s \tag{28}$$

a_s and b_s designates the complex Fourier coefficients:

$$a_s = \frac{1}{n}\sum_{j=0}^{n-1} \ddot{u}(t)e^{-i\omega_s t},\quad b_s = \frac{1}{n}\sum_{j=0}^{n-1} \ddot{u}(t)e^{i\omega_s t} \tag{29}$$

and each term in Eq. 27 is a harmonic motion oscillating with frequency ω_s.

If the series in Eq. 27 represent the motion in a layer m, a new series representing the motion in any other layer n, is obtained by applying the appropriate amplification factor from Eq. 22 to each term in the series:

$$\ddot{u}_n(t) = \sum_{s=0}^{n/2} A_{m,n}(\omega_s)\cdot(a_{m,s}e^{i\omega_s t} + b_{m,s}e^{-i\omega_s t}) \tag{30}$$

The representation of a discrete motion with its Fourier transform gives an exact representation of the motion at the discrete points $t = j\cdot\Delta t$, $j = 0,\ldots,n-1$. Cyclic repetition of the motion with the period $T = n\cdot\Delta t$

is implied in the solution. The solution applies, therefore, to an infinite train of identical accelerograms rather than the given single accelerogram. For systems with damping this is not of any significant consequence since the individual accelerograms can be separated by a quiet zone of zeros causing the responses from one cycle to damp out before the beginning of the next cycle.

The Fourier Transformation can be performed in several ways. The SHAKE program utilizes the Fast Fourier Transform algorithm developed by Cooley and Tukey (1965), which is faster by a factor n/logn over the conventional method. This technique computes all values in the series simultaneously. The method requires that the number of terms in the series be some power of 2. A typical analysis using an acceleration record of 800 terms with time-step Δt = .02 sec. will use 1024 values in the Fast Fourier Transform, with all values between 800 and 1024 set equal to 0. This will satisfy both the requirements of a quiet zone after the acceleration record and that the total number of terms must be a power of two.

3. DESCRIPTION OF PROGRAM SHAKE

Program SHAKE computes the responses in a system of homogeneous, visco-elastic layers of infinite horizontal extent subjected to vertically travelling shear waves. The system is shown in Fig. 2. The program is based on the continuous solution to the wave-equation (Kanai, 1951) adapted for use with transient motions through the Fast Fourier Transform algorithm (Cooley and Tukey, 1965). The nonlinearity of the shear modulus and damping is accounted for by the use of equivalent linear soil properties (Idriss and Seed, 1968, Seed and Idriss, 1970) using an iterative procedure to obtain values for modulus and damping compatible with the effective strains in each layer.

The following assumptions are implied in the analysis:

1. The soil system extends infinitely in the horizontal direction.
2. Each layer in the system is completely defined by its value of shear modulus, critical damping ratio, density, and thickness. These values are independent of frequency.
3. The responses in the system are caused by the upward propagation of shear waves from the underlying rock formation.
4. The shear waves are given as acceleration values of equally spaced time intervals. Cyclic repetition of the acceleration time history is implied in the solution.
5. The strain dependence of modulus and damping is accounted for by an equivalent linear procedure based on an average effective strain level computed for each layer.

The program is able to handle systems with variation in both moduli and damping and takes into account the effect of the elastic base. The motion used as a basis for the analysis, the object motion, can be given in any one layer in the system and new motions can be computed in any other layer.

The following set of operations can be performed by the program:

1. Read the input motion, find the maximum acceleration, scale the values up or down, and compute the predominant period.
2. Read data for the soil deposit and compute the fundamental period of the deposit.
3. Compute the maximum stresses and strains in the middle of each sub-layer and obtain new values for modulus and damping compatible with a specified percentage of the maximum strain.

4. Compute new motions at the top of any sublayer inside the system or outcropping from the system.
5. Print, plot and punch the motions developed at the top of any sublayer.
6. Plot Fourier Spectra for the motions.
7. Compute, print and plot response spectra for motions.
8. Compute print and plot the amplification function between any two sublayers.
9. Increase or decrease the time interval without changing the predominant period or duration of the record.
10. Set a computed motion as a new object motion. Change the acceleration level and predominant period of the object motion.
11. Compute, print and plot the stress or strain time-history in the middle of any sublayer.

These operations are performed by exercising the various available options in the program. A list of these options is given in Section 5, Required Input Data.

4. SYSTEM AND OPERATION DOCUMENTATION

4.1 Computer equipment

The program has been developed on a CDC 6400 computer using FORTRAN IV language. The CDC 6400 has a 131 k core memory and uses a 60 bit words. The program has been run without modifications on CDC 6500, 7600 and UNIVAC 1108 computers, and with minor modifications on IBM 360 and 370 computers.

4.2 Storage requirements

The program requires approximately 50,000 octal words of storage excluding the blank common X. The additional storage is a function of the maximum number of terms used in the Fourier Transform as shown in Table 1.

Table 1. Storage Requirements

Number of terms	Length of array X	Field length octal
0	0	50,000
512	3220	57,000
1024	6420	65,000
2048	12820	102,000
4096	25620	134,000
8192	51220	220,000

4.3 Runtime

The runtime is a function of the number of terms, n, used in the Fourier Transformation and of the number of sublayers in the deposit. The time involved in the Fast Fourier Transformation is proportional to $n \cdot \log n$; all other operations are approximately proportional to n. In the computation of strain compatible soil properties, the time will also increase in proportion to the number of sublayers.

For the example run, Sect. 6, the approximate run times on the CDC 6400 are shown in Table 2.

Table 2. Runtimes.

Number of terms	Time interval, sec.	Run time sec.
512	.04	45
1024	.02	80
2048	.01	170

5. REQUIRED INPUT DATA

5.1 Organization of input data.

Following is a description of the operations performed by the different options, the required format for the input data, and explanations of some of the input parameters. The input format is also described at the beginning of the main program, see listing sect. 8.3.

The various options can be executed and repeated in any logical sequence. The operations in an option will be performed on the data given or computed in the program when the option is called, and the data may be changed at any time during the execution by repeating the option with new data.

For example, in order to compute new motions in a soil deposit,(Option 5) ob motion (Option 1), soil profile data (Option 2), specification of location of object motion (Option 3), dynamic soil property-strain relation (Option 8), and strain iterations (Option 4--if strain compatible properties are desired), must precede Option 5. Soil responses for a new (additional) soil deposit may be obtained by repeating Options 2, 3, 4, and 5. The last-read soil deposit may be subjected to a new earthquake by repeating Options 1, 4, and 5

5.2 Initialization card (I5,F10.0)

Cols. 1-5 MAMAX Maximum number of terms to be used in the Fourier Transformation in any of the problems to be run. Must be a power of 2 such as 512, 1024, 2048, etc.

6-15 SKO Coefficient of earth pressure at rest for sand layers. If blank the value is set equal to 0.45. May be left blank if all layers are clay.

After the initialization card follows one run option card.

5.3 Run option card (I5)

Cols. 1-5 KK Run of option

0 - stop, no more data
1 - read input motion, and set as object motion
2 - read soil profile data
3 - assign the object motion to a specified sublayer
4 - iterate to obtain strain—compatible soil properties
5 - compute new motions at the top of specified sublayers, print maximum accelerations and punch acceleration time history
6 - print or punch acceleration time history of object motion or any specified computed motion
7 - modify object motion or set the motion in any specified sublayer as new object motion
8 - read relations between dynamic soil properties and strain
9 - compute response spectra for any specified motion
10 - increase time interval in motions
11 - decrease time interval in motions
12 - plot Fourier Spectrum of object motion
13 - compute and plot Fourier Spectrum of motion in any specified sublayer
14 - plot acceleration time history of object motion or any specified computed motion
15 - compute and plot amplification function between any two specified sublayers
16 - compute and plot stress or strain history in the middle of any specified sublayer.

After the run option card follows the data set for the selected option:

5.4 Data cards and explanetory notes for the various options

Option 1. Read Input Motion.

Operations performed

(1) Acceleration values are read from cards.

(2) The sequence of the cards is checked.

(3) The maximum acceleration value in the record is found.

(4) The acceleration values may be scaled either by a specified factor or to a specified maximum acceleration.

(5) Trailing zeros are added to the record to obtain sufficient length on the quiet zone [(a)] and a total number of values which are a power of 2.

(6) The higher frequencies in the record are removed and the maximum acceleration in the modified record is found--optional

(7) The motion is set as the new object motion.

Data Cards

1st Card (2I5,F10.0,5A6)

Cols.	1-5	NV	Number of acceleration values to be read from cards.
	6-10	MA [(a)]	Number of values to be used in Fourier transform. Must be a power of 2.
	11-20	DT [(b)]	Time interval between acceleration values (sec.)
	22-50	TITLE(I)	Identification for earthquake.

2nd Card (3F10.0)

Cols.	1-10	XF	Multiplication factor for acceleration values. Used only if XMAX is 0, left blank otherwise.
	11-20	XMAX	Maximum acceleration value to be used. The acceleration values in the record will be scaled to give maximum acceleration = XMAX, unless XF is left blank.
	21-30	FMAX [(c)]	Maximum frequency to be used in the calculations. Acceleration amplitudes at all frequencies greater than FMAX are set equal to 0.

3rd and consecutive cards. Acceleration record. (8F9.6,I7)

Cols.	1-72	X(I)	8 acceleration values. (g's)
	73-79	K	Card number. Warning will be given for cards not in sequence.

Explanatory notes for Option 1.

(a) The acceleration values between NV and MA are set equal to 0. in the program. Cyclic repetition of the motion is implied in the Fourier transform and a quiet zone of 0.'s or low values are necessary to avoid interference between the cycles. For most problems a quiet zone of 2-4 seconds is adequate with longer time required for profiles deeper than about 250 ft and/or damping values less than about 5 percent.

(b) The predominant period of the earthquake record can be changed by altering the time interval Δt from that originally assigned to the acceleration record. If the original record has time interval Δt_o and corresponding predominant period T_1, a new predominant period T_2 is obtained by changing the time interval to

$$\Delta t_2 = \frac{T_2}{T_1} \Delta t_1$$

(c) Frequencies above 10-15 c/sec carry a relatively small amount of the energy in earthquake motions, and the amplitudes of these frequencies can often be set equal to 0 without causing any significant change in the responses within a soil system. Table 3 shows the maximum accelerations and strains in the soil system used in the example run, sect. 6, computed for the Pasadena motion with time interval 0.02 sec and a maximum frequency of 25 c/sec. Results are also shown for the same motion with all amplitudes above 5 c/sec set equal to 0. The difference in maximum accelerations was less than 6.5% and in maximum strains less than 0.7% in the two cases. The difference in response spectral values was less than 1% for periods above 0.2 sec and less than 10% for periods from .0 to 0.2 sec.

Table 3. Effect of the Higher Frequencies on the Maximum Accelerations and Strains.

Depth	Maximum acceleration, g's		Difference %	Maximum strain, %		Difference %
	f_{max} = 25 c/sec	5 c/sec		f_{max} = 25 c/sec	5 c/sec	
0	.0971	.0962	.9			
				.00725	.00724	.1
7	.0958	.0949	.3			
				.1292	.1283	.7
20	.0600	.0599	.1			
				.0391	.0390	.3
30	.0553	.0556	.6			
				.0287	.0287	-
42	.0508	.0507	.2			
				.00982	.00989	.7
62	.0470	.0469	.2			
				.0505	.0504	.2
80	.0319	.0299	6.3			
				.0349	.0348	.3
100	.0239	.0235	1.7			
				.0320	.0319	.3
120	.0178	.0189	6.2			

In the computation of responses in deep soil systems from a motion given near the surface of the deposit, errors in the higher frequencies will be amplified and may cause erroneous results. To avoid this source of error, the amplitudes of all frequencies above 10-20 c/sec. may be set equal to 0., since these frequencies generally are of little interest and do not affect the response. Several runs should be performed with different amounts of the higher frequencies removed to investigate the effect on the response and to ensure a stable solution.

Removal of the higher frequencies in a motion has a smoothening effect on the acceleration time history as shown in Fig. 5 for a segment of the Pasadena motion. In this case the maximum acceleration for the modified and original motion were approximately equal, but the maximum accelerations may decrease or increase with the removal of the higher frequencies depending on the shape of the acceleration curve near the maximum value.

Option 2. Read Data for Soil Deposit.

Operations performed

(1) The properties of the soil deposit are read from cards.

(2) The sequence of the layer cards is checked.

(3) The layers are subdivided into sublayers—optional.

(4) Effective pressures in the middle of each sublayer are computed.

(5) The fundamental period of the deposit is computed.

Data Cards

1st Card (3I5,6A6)

Cols.	1-5	MSOIL	Soil deposit number. Can be left blank.
	6-10	ML[(a)]	Number of layer cards to be read including card for halfspace. There is one card for each layer whose properties are individually specified.[(b)]

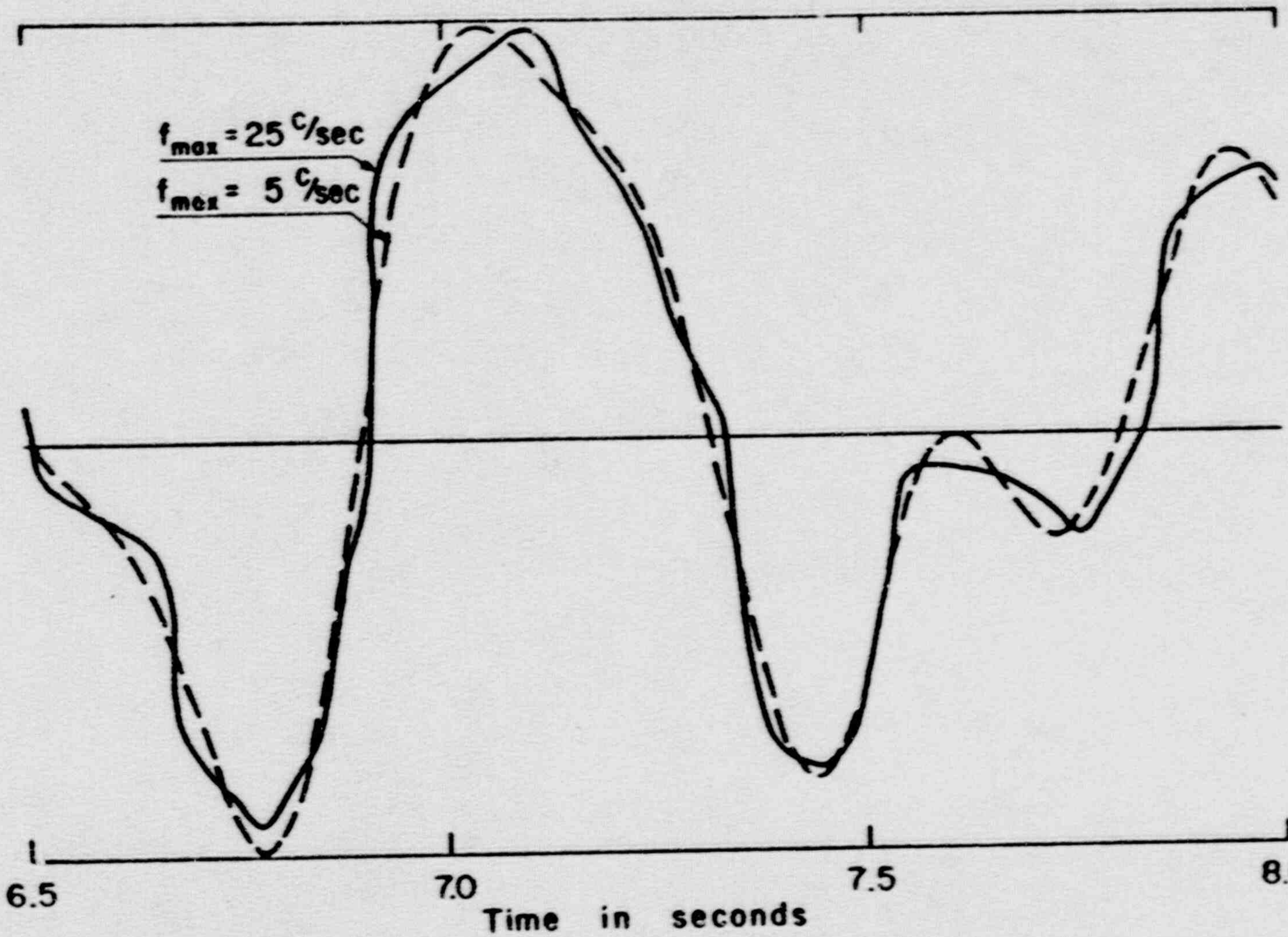


Fig. 5 EFFECT OF THE HIGHER FREQUENCIES ON THE ACCELERATION TIME-HISTORY

Cols. 11-15 MWL — Number of first submerged sublayer [(b)]. [If no ground water table present, put groundwater table at top of halfspace.]

17-51 IDNT(I) — Identification for soil profile.

2nd and consecutive cards. One card for each layer including halfspace. (3I5,6F10.0,F5.0)

Cols. 1-5 K — Layer number. The layer cards must be in sequence with the surface layer as layer 1. Note that the number of layers may be $\leq$ the number of sublayers[(b)].

10 TYPE[(c)] — Soil type
- 1 - clay
- 2 - sand
- 3 - rock

11-15 NLN[(a,b)] — Number of sublayers in layer K. The K^{th} layer will be divided into NLN sublayers of thickness = HL/NLN.*

16-25 HL[(a)] — Layer thickness (ft.)

26-35 GMOD[(d)] — Initial estimate of shear modulus (kips/sq.ft.) Not necessary if VS is given.

36-45 B[(d)] — Initial estimate of critical damping ratio (decimal).

46-55 W — Unit weight (kips/cu. ft.).

56-65 VS[(d)] — Initial estimate of shear wave velocity (ft/sec). Not necessary if GMOD is given.

66-75 FACTOR[(c)] — Factor for shear modulus
- Clay - F_c = undrained shear strength (kips/sq. ft.)
- Sand - F_s = factor modifying the average curve read in under Option 8. Set F_s = 1. for no change.
- Rock - F_R = Shear wave velocity for low strain values—in thousands of ft./sec.

76-80 BFAC — Factor modifying the standard damping curve read in under Option 8. For example, a factor of 1.2 increases each and every value by 20 percent.

For the elastic half space, soil layer card number ML, it is sufficient to give values for K, GMOD or VS and W.

---

*Maximum total number of sublayers including the base is 20.

Explanatory notes for Option 2.

(a) With th wave propagation method the responses can be computed in a homogeneous layer of any thickness. A soil deposit will, however, have varying properties not only due to the variation in the soil itself but also due to the differences in the strain-level induced during shaking. Since the soil deposit must be represented by a set of homogeneous layers, each with a constant value of modulus and damping, the thickness of each layer must be limited based on the variation in the soil properties. For a fairly uniform deposit, a sublayer thickness increasing from about 5' at the surface to 50-200' below 100' depth should give sufficient accuracy. Accuracy may be checked by making a trial run and comparing results with a subsequent run where more layers and/or sublayers are used.

(b) The division of a layer into sublayers is for convenience to avoid punching of several cards with the same properties, and all sublayers are treated as separate layers in the following computations. The sublayers are numbered consecutively starting at the top of the soil deposit and the halfspace is counted as the last layer and the last sublayer in the deposit.

(c) Computations of shear moduli for the different soil types are based on the following expressions:

Clay $G_c = K_c \cdot F_c$

Sand $G_s = K_s \cdot 1000 \cdot (\sigma'_m)^{1/2} \cdot F_s$

Rock $G_R = K_R \cdot \rho \cdot (1000 \cdot F_R)^2/2000.$

where

K = strain function given in Option 8.

F = factor given as input (FACTOR)

ρ = mass density in kips/cu. ft.

σ'_m = mean effective pressure (psf).

The strain function for clays, K_c, gives the average relationship between G/S_u and strain for saturated clays. While the undrained shear strength of the clay, S_u, is normally used in this modulus-strain relation, the factor for clay, F_c, should be given a value which gives the correct modulus-strain relation; thus F_c is not necessarily equal to S_u. If the modulus of the clay is found from seismic investigations, the value of F_c should be set to G_c/K_c where K_c is the value for 10^{-4} percent strain in the curve given in Option 8.

(d) The modulus and damping are in general used as initial values on the first iteration for the computation of strain-compatible properties, but they can also be used directly to compute the responses for the values given, by omitting Option 4. Typical values of the modulus for strong shaking are of the order of 500 kips/sq. ft. near the surface increasing to 3000 kips/sq. ft. at 100-200' depth for sand, 500-2000 kips/sq.ft. for clay with values as low as 50-100 kips/sq. ft. for soft clay. Usually 3-5 iterations are sufficient to obtain strain compatible values within a 5-10% error limit.
The results are not highly sensitive to errors in the damping ratio and values selected between 0.05 to 0.15 will usually give strain-compatible values with 2 to 3 iterations.

Option 3. Assign Object Motion to a Specified Sublayer.

Operations performed

The object motion is assigned to the top of one sublayer in the soil deposit.

Data Cards

1st Card (2I5)

Cols.	1-5	IN	Number of sublayer where object motion is assigned.
	6-10	INT	Type of sublayer 0 - Outcropping[a] sublayer 1 - sublayer within profile

Explanatory notes to Option 3.

[a] See Section 2.2.

Option 4. Obtain Strain Compatible Soil Properties.

Operations performed

(1) Parameters for the iterations are read from card.

(2) Maximum strains, stresses and times for the maxima are computed in the middle of each sublayer.

(3) Effective strains are obtained from the maximum strains and used to compute new soil properties.

(4) The operation is repeated until strain-compatible soil properties are obtained within a given error limit or until a specified maximum number of iterations is reached.

(5) The fundamental period of the deposit is computed after the final iteration.

(6) A set of soil data cards with the new strain compatible properties is punched--optional.

Data Cards

1st Card (2I5,2F10.0)

Cols. 1-5	KS[a]	Set equal to 1 for punched set of soil data cards with the soil properties after final iteration. Leave blank if punched cards are not wanted.
6-10	ITMAX[b]	Maximum number of iterations.
11-20	ERR[b]	Maximum acceptable difference between the last-used modulus and damping values and the strain-compatible values (percent).
21-30	PRMUL[c]	Ratio between effective strain and maximum strain (decimal).

Explanatory notes for Option 4.

(a) The most time consuming part of the computations is to obtain strain compatible soil properties. A set of soil data cards with strain-compatible properties may save computer or punching time if additional computer runs are to be made subsequently.

(b) The iterations stop when the specified maximum number of iterations (ITMAX) is reached or when the difference between the modulus and damping used and the strain-compatible modulus and damping values is less than the acceptable difference (ERR). Usually 3-5 iterations are sufficient to obtain an error of less than 5-10%. The values given as "new values" in the final iteration are used in all computations following Option 4, and the actual error is less than the error values given in the final iteration.

(c) The effective strain is used to compute new soil properties. The ratio between the effective and the maximum strain has been empirically found to be between 0.5 and 0.7. The responses, however, are not highly sensitive to this value and an estimate between 0.55 to 0.65 is usually adequate, with the higher value appropriate for giving more uniform strain histories.

Option 5. Compute Motion in Specified Layers.

Operations performed

(1) The acceleration time history is computed at the top of specified sublayers.

(2) The maximum acceleration and times for maxima are printed for the computed motions.

(3) The computed acceleration time histories may be punched--optional.

(4) The acceleration time histories may also be printed or plotted (Option 6, 7 and 14)[a].

Data Cards

1st Card (15I5)

Cols.	1-75	LL5(I)	Array showing the numbers of the sublayers at the top of which the motion is to be computed. Maximum of 15 locations.

2nd Card (15I5)

Cols.	1-75	LT5(I)	Array specifying types of above sublayers. 0 - outcropping [b] sublayer 1 - sublayer within profile

3rd Card (15I5)

Cols.	1-75	LP5(I)[a]	Array with mode of output for the computed motions. 0 - max. acceleration value only printed. 1 - punched cards giving acceleration time history in addition to the printed maximum acceleration value.

Explanatory notes for Option 5

(a) The acceleration time histories can be printed or plotted through the use of Option 7 where a specified motion is set as the new object motion. Subsequent use of Options 6 and 14 give respectively a printed and a plotted output of the acceleration time history of the motion.

(b) See section 2.2.

Option 6. Print or Punch Object Motion.

Operations performed

(1) Maximum acceleration and time at which maximum occurs are found.

(2) The object motion is printed--optional.

(3) The object motion is punched on cards--optional.

Data Cards

1st Card (I5)

Col. 5 K2 Selects mode of output.

K2 = 0 Max. acc. only
1 Punched output
2 Printed and punched output.

Option 7. Change Object Motion.

Operations performed

(1) A motion at the top of a specified sublayer can be set as the new object motion and printed or punched (Option 6) or plotted (Option or used for subsequent computations--optional.

(2) The time step in the object motion can be changed--optional.

(3) The acceleration level in the object motion can be changed--optional.

Data Cards

1st Card (2I5,2F10.0)

Cols. 1-5 LL1 Number of sublayer. Use 0 if object motion originally assigned is to be retained[a].

6-10 LT1 Type of above sublayer
0 - outcropping [c] sublayer
1 - sublayer within profile

11-20 XF Multiplication factor for acceleration values--1. for no change.

21-30 DTNEW New timestep[b].

Explanatory notes for Option 7

(a) The acceleration level and timestep can be changed either on the motion originally set as the object motion, or on the computed

motion which is set as the new object motion through Option 7.

(b) A change in time interval will change the predominant period of the motion. If the time interval and predominant period of the original motion are Δt_1 and T_1, respectively, a new predominant period T_2 is obtained by changing the time interval to

$$\Delta t_2 = \frac{T_2}{T_1} \Delta t_1$$

(c) See section 2.2.

Option 8. Read the relation between the Effective Strain and the Dynamic Properties

Operations performed

(1) Effective strain values with corresponding values for damping and moduli are read from cards.

(2) Parameters are computed for interpolation of modulus and damping values using a linear semilogarithmic relation between the given values.

(3) The relationship between the dynamic properties and the strain is plotted--optional.

Data Cards

1st Card (3I5,F10.0,10A6)

Cols.	1-5	NSOILT	Number of different soil or rock types to be read. Maximum 4.[a]
	10	NPL[b]	Set equal to 1 for plot of curves.
	11-15	NN[b]	Number of strain-values in each logarithmic unit to be plotted.
	16-25	SC	Maximum value of the ordinate in the plotting.
	26-80		Title or identification data.

Next follows two sets of cards for each soil or rock type. The first set gives the relationship between the shear modulus parameters (C) and the effective strains; the second set give the relation between the critical damping ratios and the effective strains. Typical data is shown on page 40.

First Set:

1st Card (I5,F5.0,11A6)

Cols.	1-5	NV(L)	Number of strain values to be read. Maximum 20.
	6-10	FPL(L)[(b)]	Multiplication factor for shear-modulus parameter. Used for plotting only.[(b)]
	12-76	ID(L,I)	Identification for first data set. Used for plotting only.

2nd and consecutive cards (8F10.0)

Cols.	1-80	X(L,I)	Effective strain values in percent beginning with the lowest value. 8 values per card with maximum of 20 values.

Consecutive cards (8F10.0)

Cols.	1-80	Y(L,I)	Values of the shear modulus parameter[(c)] corresponding to the strain values given above. Eight values per card with maximum of 20 values.

Second Set:

The input format for the second set is identical to that for the first set with values of critical damping ratios in percent instead of the values for the shear modulus parameter.

<u>Explanatory notes for Option 8</u>.

(a) Three different soil or rock types can be used in the program as described in Option 2. The relationships between effective strains and the dynamic properties must be read in the same sequence as the soil type using the notation:

1 - Clay

2 - Sand

3 - Rock

(b) The values for the shear modulus parameter and the damping can be plotted against the effective strains. If plotting is specified (NPL = 1), values for the shear modulus parameter and damping are

computed for a specified number of effective strains (NN) in each logarithmic unit. The computed values should be scaled (FPL(L)) to obtain good representation of all curves on the same plot. The scaled values and the corresponding effective strains are also printed.

(c) The values are used to compute the shear modulus for the different soil types. The relationship for sand and clay used in the progra is based on the expressions given by Seed and Idriss (1970):

$$\text{Clay} \quad K_c(\gamma) = \frac{G_c(\gamma)}{S_u}$$

$$\text{Sand} \quad K_s(\gamma) = \frac{G_s(\gamma)}{1000 \cdot (\sigma_m')^{1/2}}$$

The relationship used for rock is the scaled ratio between the shea modulus at low effective strain (10^{-4} percent) and the shear modulu at a specified effective strain:

$$\text{Rock} \quad K_R(\gamma) = \frac{G(\gamma) \cdot 2000}{G(\gamma 10^{-4})}$$

Option 9. Compute Response Spectra

Operations performed

(1) The motion is computed at the top of a specified sublayer.

(2) Times for maxima in the acceleration, velocity and displacement spectra are computed and printed.

(3) Acceleration and velocity spectra may be plotted and/or punched on cards--optional.

Data Cards

1st Card (2I5)

Cols. 1-5 LL1 Sublayer number. Use 0 if the response spectra are to be computed for the object motion.

10 LT1 Type of sublayer.
0 - outcropping sublayer
1 - sublayer within profile.
The response spectra are computed for the motion the top of the sublayer. May be left blank if LL1

2nd Card (5I5)

Col. 5 ND Total number of damping values to be used. Maximum 6 values.

10 KP Set equal to 1 for punched output.

15 KAV Select plot and punch option:
- 0 - plot and/or punch velocity spectrum
- 1 - plot and/or punch acceleration spectrum
- 2 - plot and/or punch acceleration and velocity spectrum.

20 KPL Set equal to 1 for plot of spectra according to KAV. All spectra computed since last plotting will be plotted together.

25 KPER Select periods to be used in the computations:

KPER = 0
- 9 steps from 0.1 sec to 1. sec
- 5 steps from 1. sec to 2. sec
- 4 steps from 2. sec to 4. sec

KPER = 1
- 18 steps from 0.1 sec to 1. sec
- 10 steps from 1. sec to 2. sec
- 8 steps from 2. sec to 4. sec

KPER = 2
- 38 steps from 0.05 sec to 1. sec
- 20 steps from 1. sec to 2. sec
- 30 steps from 2. sec to 5. sec

KPER = 3
Logarithmic increments with 10 steps in each log. unit from 0.1 to 5.

KPER = 4
Logarithmic increment with 25 steps in each log. unit from 0.05 to 10.

3rd Card (6F10.0)

Cols. 1-60 ZLD(I) Values of critical damping ratios in decimal to be used in the spectral analysis. ND number of values must be given.

<u>Option 10. Increase the Time Interval</u>

<u>Operations performed</u>

The time interval is increased.

Data Cards

1st Card (I5)

Cols. 1-5 IFR[a] factor for increasing time interval. Must be a power of 2.

Explanatory notes for Option 10

(a) The Fourier Transformation of a given acceleration time history consists of a series of harmonic motions

$$\ddot{u}(t) = \sum_{s=0}^{n/2} (a_s e^{i\omega_s t} + b_s e^{-i\omega_s t})$$

With the harmonic motions given, acceleration values can be computed for any value of the time, t, and a new acceleration time history can be generated with a time interval different from the original.

Suppose, for example an acceleration record is given with 2048 values and a timestep $\Delta t = 0.01$ sec. Through Option 10 with IFR = 2 a new record with 1024 values and timestep 0.02 sec is generated. The acceleration values in the two records are identical at all times $n \cdot .02$ sec., $n = 1,2...1024$. The new record has a maximum frequency of 25 c/sec. compared to 50 c/sec. in the original records, and frequencies from 25 c/sec. to 50 c/sec. are lost in the operation.

Increasing the time interval reduces the computer time as shown under sect. 4.3. For computation of maximum accelerations a time interval of 0.02 sec. will generally give adequate accuracy while a time interval of 0.04 sec. may be sufficient for the computation of the stresses and strains in a deposit.

The difference in maximum accelerations and strains resulting from the use of different time intervals are shown in Tables 4 and 5 for the example run. The effect may be somewhat higher for earthquakes with lower predominant periods and for stiffer soil systems.

Option 11. Decrease the Time Interval

Operations performed

The time interval is decreased.

Data Cards

1st Card (I5)

Col. 1-5 IFR[(a)] Factor for decreasing the time interval; must be a power of 2.

Explanatory notes for Option 11.

(a) See explanation to Option 10. Through Option 11 a new time history is generated with the time interval reduced by a power of 2. Compared with the usual linear interpolation, this method has the advantage of not introducing additional frequencies to the motion.

Option 12. Plot Fourier Spectrum of Object Motion

Operations performed

(1) The Fourier Spectrum of the object motion is plotted.

(2) The spectrum may be smoothed--optional.

Data Cards

1st Card (3I5)

Cols. 5	K1	Select for plotting: 0 - Store spectrum for later plotting. Max. of 2 spectra can be plotted together. 1 - Plot all spectra stored since last plotting.
6-10	NSW[(a)]	Number of times the spectrum is to be smoothed.
11-15	N	Number of values to be plotted--maximum of 2049.

Table 4. Effect of Time Interval on Maximum Strain.

Depth	Computed Maximum Strain %		
	Δt = .01	Δt = .02	Δt = .04
3.5	.00727	.00725	.00725
13.5	.129	.129	.127
25.	.0392	.0391	.0390
36	.0287	.0287	.0285
52	.00982	.00982	.00981
71	.0505	.0505	.0505
90	.0350	.0349	.0348
110	.0320	.0320	.0316

Table 5. Effect of Time Interval on Maximum Acceleration.

Depth	Maximum Acceleration		
	Δt = .01	Δt = .02	Δt = .04
0	.0971	.0971	.0967
7	.0960	.0958	.0954
20	.0598	.0600	.0590
30	.0554	.0553	.0548
42	.0508	.0508	.0498
62	.0471	.0470	.0462
80	.0317	.0319	.0318
100	.0238	.0239	.0242
120	.0181	.0178	.0178

Explanatory notes to Option 12.

(a) The expression used to smooth the spectrum is:

$$A_i = \frac{A_{i-1} + 2A_i + A_{i+1}}{4}$$

where A_i is the acceleration amplitude for the i^{th} frequency.

Option 13. Plot Fourier Spectrum[c] of Computed Motions

Operations performed

(1) The motions at the tops of the specified sublayers are computed.

(2) The Fourier Spectra for the computed motions are plotted and printed.

(3) The spectrum may be smoothed--optional.

Data Cards

1st Card (5I5)

Cols.	1-5	LL(1)	Sublayer number.
	10	LT(1)	Type of sublayer: 0 - Outcropping[b] sublayer 1 - Sublayer within profile.
	15	LP(1)	Select for plotting: 0 - Store spectrum for later plotting; max. of 2 spectra can be plotted together 1 - Plot all spectra stored since last plotting.
	16-20	LNSW(1)[a]	Number of times the spectrum is to be smoothed.
	21-25	LLL(1)	Number of values to be plotted. Max. of 2049.

2nd Card (5I5)

As for Card 1 for a second motion. A blank card must be used if only one spectrum is to be computed.

Explanatory notes for Option 13

(a) See Option 12.

(b) See section 2.2.

(c) See section 2.3.

Option 14. Plot Time History of Object Motion[(a)].

Operations performed

The time history of the object motion is plotted.

Data Cards

1st Card (2I5)

Cols.	1-5	NSKIP	Number of values skipped in the plotting. 0 - every value is plotted 1 - every second value is plotted etc.
	6-10	NN	Number of values to be plotted. Max. of 2049 values.

Explanatory notes to Option 14.

(a) The time history of a computed motion can be plotted by setting this motion as the object motion through Option 7.

Option 15. Compute Amplification Spectrum.

Operations performed

(1) The amplification spectrum between any two sublayers in a given soil system is computed.

(2) The maximum amplification and the corresponding period are printed.

(3) The amplification spectrum may be plotted and printed—optional.

Data Cards

1st Card (5I5, F5.0,8H6)

Cols.	1-5	LIN[(a)]	Number of first sublayer.
	6	LINT	Type of first sublayer 0 - outcropping[(b)] sublayer 1 - sublayer within profile
	11-15	LOUT[(a)]	Number of second sublayer.
	20	LOTP	Type of second sublayer 0 - outcropping sublayer 1 - sublayer within profile.
	25	KP	Select for plotting: 0 - Store spectrum for later plotting. Maximum of 8 spectra can be stored. 1 - Plot all spectra stored since last plotting.

26-30	DFA	Frequency steps. The amplification factor is computed for the first 200 frequencies with interval DFA c/sec. beginning at 0.
32-78	IDAMP(I)	Identification.

Explanatory notes to Option 15.

(a) The amplification factors are computed from the first sublayer to the second.

(b) See section 2.2.

Option 16. Compute Stress or Strain History in the Middle of Specified Sublayers.

Operations performed

(1) The stress and/or strain time history in the middle of any two specified sublayers are computed.

(2) The computed time histories may be plotted or punched on cards.

Data Cards

1st Card (5I5,F10.0,5A6)

Cols.		
1-5	LLL(1)	Sublayer number. The stress or strain history is computed on the middle of the sublayer.
10	LLGS(1)	Select type of response: 0 - strain 1 - stress
15	LLPCH(1)	Set equal to 1 for punched output.
20	LLPL(1)	Set equal to 1 for plotting.
21-25	LNV(1)	Number of values to be plotted; maximum of 20
26-35	SK(1)	Scale for plotting—i.e. maximum value of ordinate. If blank, the largest value in the response is set as the maximum value of the ordinate.
37-65	ID(1,)	Identification.

2nd Card. As for Card 1 for second sublayer. Use blank card if only one response is to be computed.

6. EXAMPLE RUN

6.1 Selection of soil system and input motion.

An example problem is shown in Fig. 6. Maximum accelerations, stresses and strains in the soil deposit and response spectra for the surface accelerations are wanted for a magnitude 7.4 earthquake occuring 100 miles from the site.

Based on the relations given by Seed and Idriss (1970), the soil system shown on Fig. 7 was selected for analysis. The factors used for clay are equal to the undrained shear strength in kips/sq. ft. The factors for sand are estimated from relative densities and content of gravel.

The motion in rock for a magnitude 7.4 earthquake 100 miles from the causative fault is estimated to have maximum acceleration of .02g and a predominant period of 0.65 sec (Schnabel and Seed, 1972; Seed et al., 1969). Among the available strong motion records, the Pasadena record from the 1952 Kern County earthquake seems to have characteristics most similar to those desired. The magnitude of the earthquake was 7.7, the record was obtained some 75 miles from the fault, the maximum acceleration was 0.057g and the predominant period was 0.65 sec. Modification of this record to give a maximum acceleration 0.02g gives the desired characteristics for the motion in an outcropping rock formation near the example site.

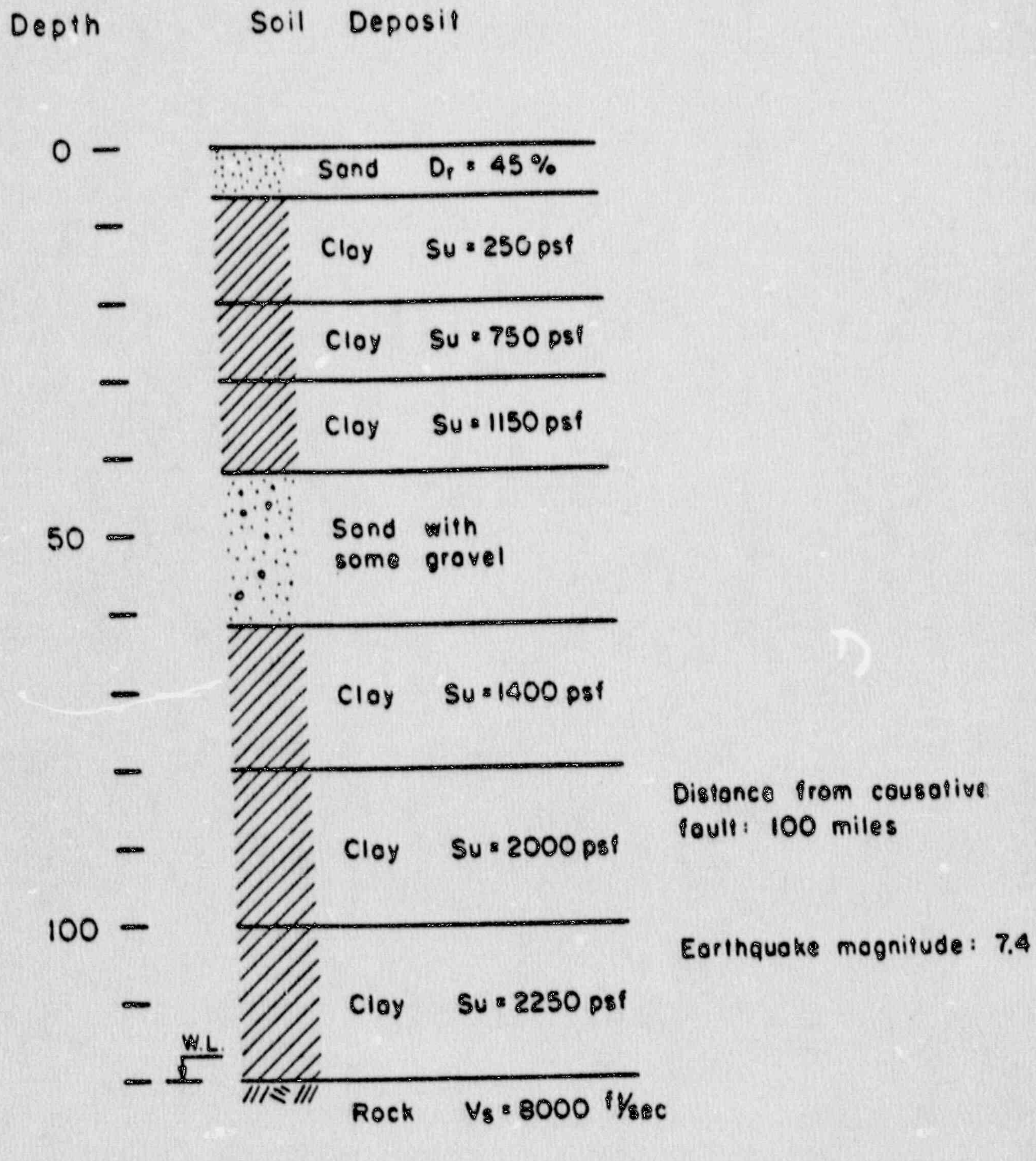


Fig. 6 EXAMPLE PROBLEM

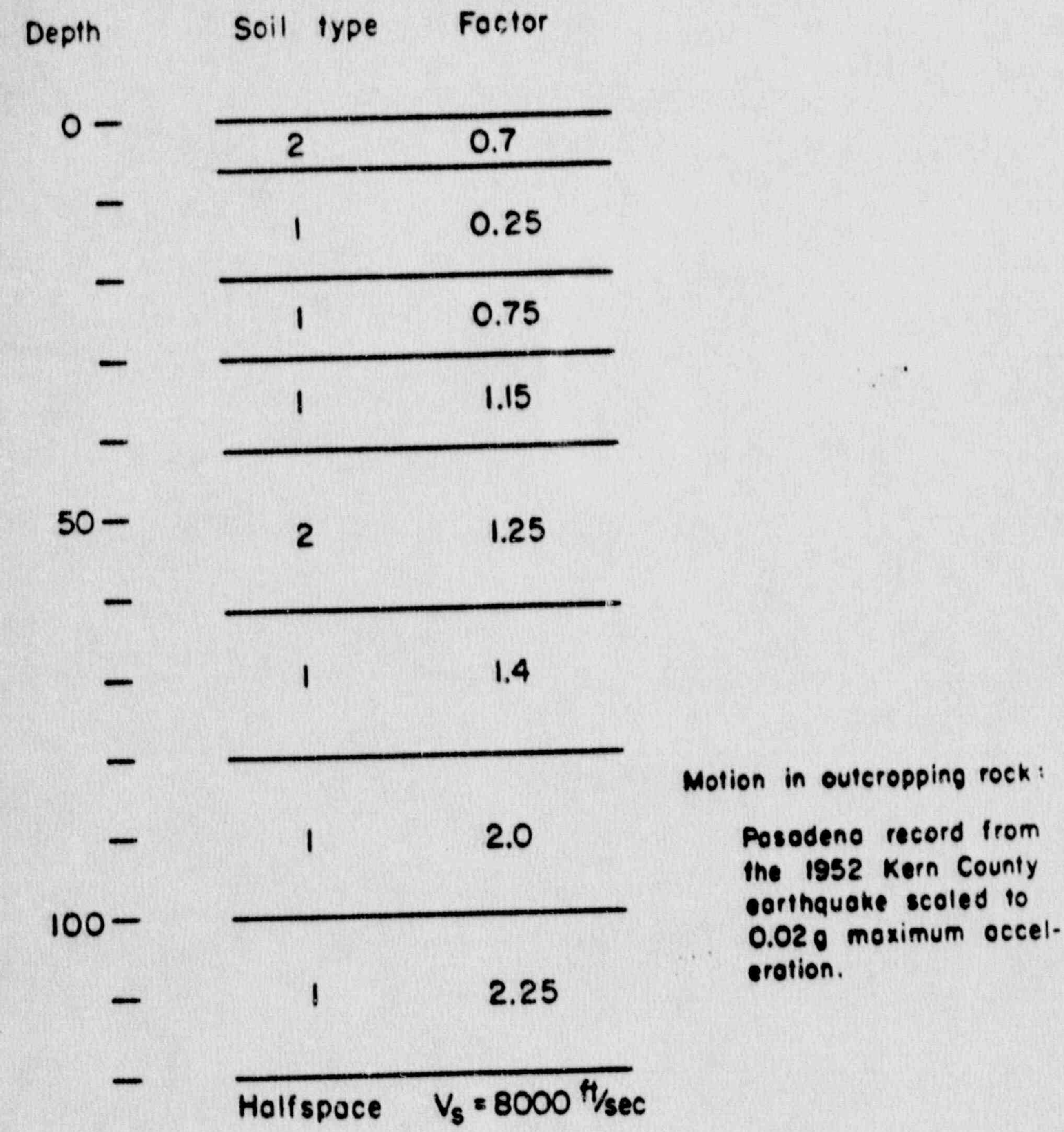


Fig. 7 SYSTEM USED IN THE ANALYSIS OF THE EXAMPLE PROBLEM

6.2 Input data for the analysis.

INITIALIZATION 1 CARD

1.......10.......20.......30.......40.......50.......60.......70.......80

[illegible]

OPTION 0 [illegible] CARDS

1.......10.......20.......30.......40.......50.......60.......70.......80

[illegible]

OPTION 1 [illegible] CARDS

1.......10.......20.......30.......40.......50.......60.......70.......80

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12
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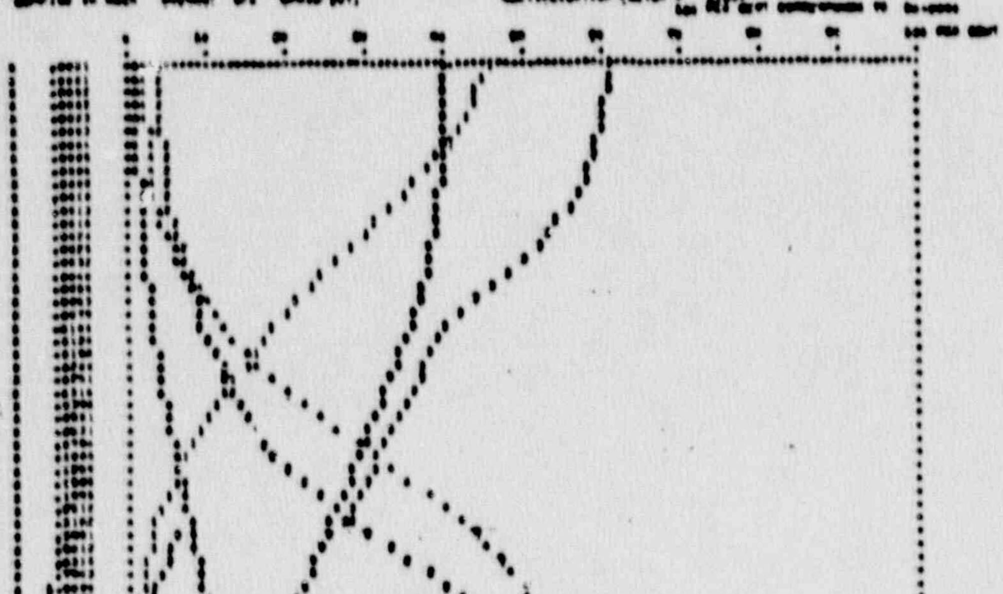
```
OPTION 7          10 CARDS
1.......10........20........30........40........50........60........70........80

7
1   0   0     PROBABLE SIZE                                        .700 1.00
1   7   1      7.39 1000.      .99          .120                   .250 1.00
1   1   1     11.90  200.      .1           .100                   .750 1.00
1   1   1     19.99 1000.      .99          .100                   1.15 1.00
1   1   1     12.90 1900.      .99          .100                   1.250 1.00
1   2   1     23.90 2000.      .99          .125                   1.5  1.
1   1   1     10.90 1000.      .99          .125                   2.000 1.50
1   1   1   90.       2000.    .99          .125                   2.250 1.00
1   1   1   25.       2500.    .99          .125
0                              0.           .150    9000.

OPTION [illegible]        [illegible] CARDS
1.......10........20........30........40........50........60........70........80

0   0

OPTION [illegible]        [illegible] CARDS
1.......10........20........30........40........50........60........70........80

0   0   0.     .05

OPTION [illegible]        [illegible] CARDS
1.......10........20........30........40........50........60........70........80

[illegible]
```

1.......10.......20.......30.......40.......50.......60.......70.......80

1.......10.......20.......30.......40.......50.......60.......70.......80

6.3 Computer output from the analysis.



[illegible]

[illegible]

[illegible]

EARTHQUAKE = PASADENA [illegible]
SOIL PROFILE = EXAMPLE SITE

ITERATION NUMBER [illegible]
THE CALCULATION HAS BEEN CARRIED OUT IN THE TIME DOMAIN WITH EFF. STRAIN = [illegible] MAX. STRAIN

LAYER	TYPE	DEPTH	EFF. STRAIN	NEW DAMP.	DAMP USED	ERROR	NEW G	G USED	ERROR
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

VALUES IN TIME DOMAIN

LAYER	TYPE	THICKNESS FT	DEPTH FT	MAX STRAIN PRCNT	MAX STRESS PSF	TIME SEC
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

EARTHQUAKE = PASADENA [illegible]
SOIL PROFILE = EXAMPLE SITE

ITERATION NUMBER [illegible]
THE CALCULATION HAS BEEN CARRIED OUT IN THE TIME DOMAIN WITH EFF. STRAIN = [illegible] MAX. STRAIN

LAYER	TYPE	DEPTH	EFF. STRAIN	NEW DAMP.	DAMP USED	ERROR	NEW G	G USED	ERROR
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

VALUES IN TIME DOMAIN

LAYER	TYPE	THICKNESS FT	DEPTH FT	MAX STRAIN PRCNT	MAX STRESS PSF	TIME SEC
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

MAXIMUM AMPLIFICATION = [illegible]
FOR FREQUENCY = [illegible]
PERIOD = [illegible]

[illegible] OPTION [illegible] *** COMPUTE [illegible]

[illegible]
[illegible]

LAYER	DEPTH	MAX. ACC.	TIME	[illegible]	ACC. RATIO	[illegible]
WITHIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WITHIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WITHIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WITHIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WITHIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WITHIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WITHIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WITHIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WITHIN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible] OPTION [illegible] *** COMPUTE RESPONSE SPECTRUM

[illegible]

[illegible]

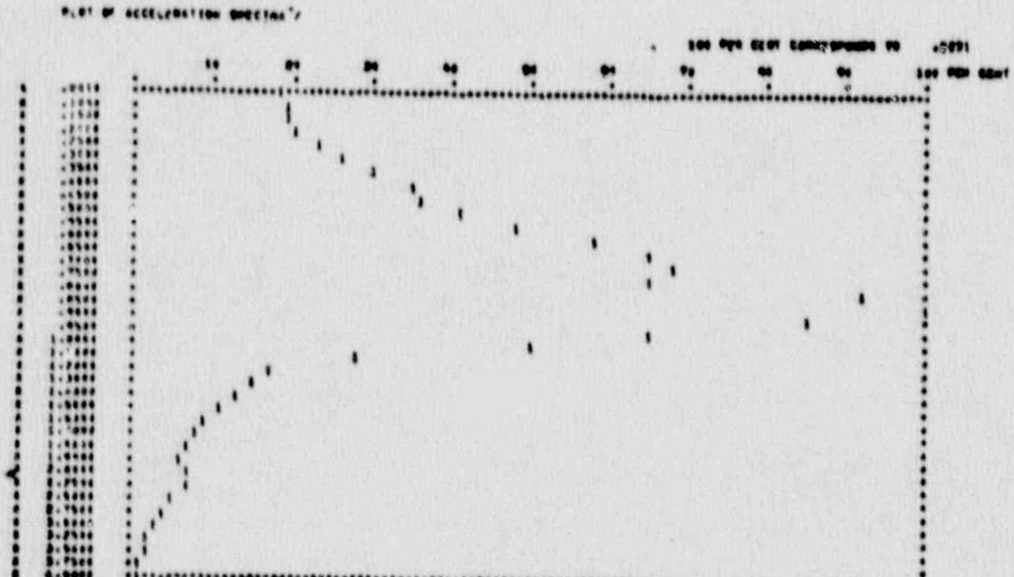
SPECTRAL VALUES FOR
PASADENA 1952 — EXAMPLE SITE — DAMPING RATIO = .05

NO.	PERIOD SEC.	REL. DISP. FT.	REL. VEL. FT./SEC.	PSEUDO-REL. VEL. FT./SEC.	ABS. ACC. G.	PSEUDO-ABS. ACC. G.	FREQ. C/SEC.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

VALUES IN PERIOD RANGE .1 TO 2.5 SEC.

AREA OF ACC. RESPONSE SPECTRUM : [illegible]
AREA OF VEL. RESPONSE SPECTRUM : [illegible]
MAX. ACCELERATION RESPONSE VALUE : [illegible]
MAX. VELOCITY RESPONSE VALUE : [illegible]

PLOT OF ACCELERATION SPECTRA



PERIOD IN SEC.

CURVE 1 - PASADENA 1952 EXAMPLE SITE

PERIOD	CURVE 1
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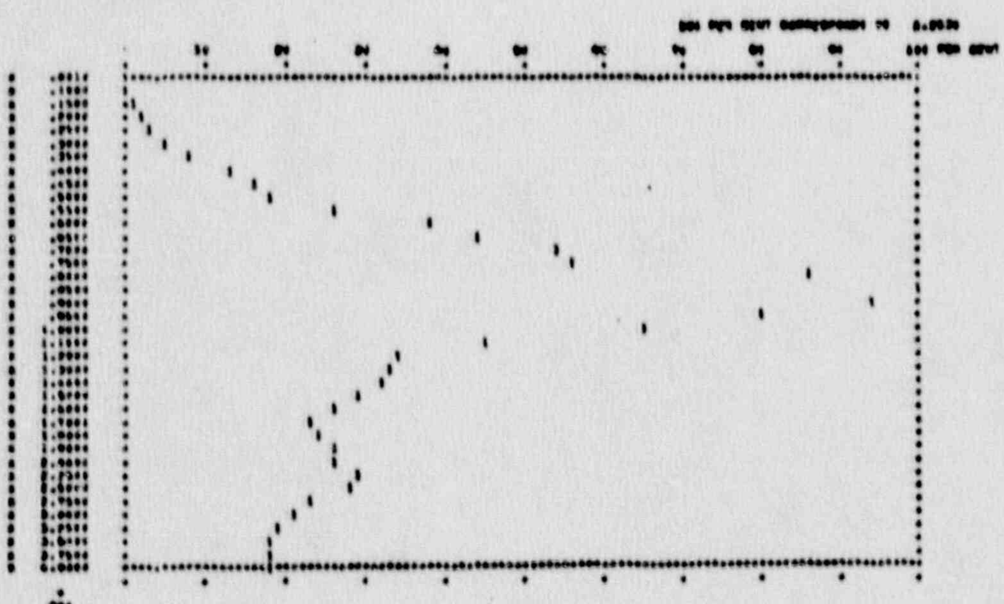
PLOT OF VELOCITY SPECTRA



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.5500	[illegible]
.6000	[illegible]
.6500	[illegible]
.7000	[illegible]
.7500	[illegible]
.8000	[illegible]
.8500	[illegible]
.9000	[illegible]
.9500	[illegible]
1.0000	[illegible]
1.1000	[illegible]
1.2000	[illegible]
1.3000	[illegible]
1.4000	[illegible]
1.5000	[illegible]
1.6000	[illegible]
1.7000	[illegible]
1.8000	[illegible]
1.9000	[illegible]
2.0000	[illegible]
2.2500	[illegible]
2.5000	[illegible]
2.7500	[illegible]
3.0000	[illegible]
3.2500	[illegible]
3.5000	[illegible]
3.7500	[illegible]
4.0000	[illegible]

7. PROGRAM IDENTIFICATION AND ABSTRACT

7.1 Program Identification

1. Program title: Vertical propagation of shear waves through a horizontally layered soil/rock system.

2 Program name: SHAKE.

3. Writers: Per B. Schnabel, Research Assistant
   John Lysmer, Associate Professor of Civil Engineering.

4. Organization: Geotechnical Engineering
   Department of Civil Engineering
   University of California
   Berkeley, California 94720

5. Date: December, 1972.

6. Version: 2

7. Source language: FORTRAN IV

7.2 Abstract

The program computes the response in a horizontally layered soil rock system subjected to transient, vertical travelling shear waves. The method is based on Kanai's solution to the wave equation and the Fast Fourier Transform algorithm. The motion used as basis for the analysis can be applied to any layer in the system. Systems with elastic base and with variable damping in each layer can be analyzed. Equivalent linear soil properties are used with an iterative procedure to obtain soil properties compatible with the strains developed in each layer. A varied set of operations of interest in earthquake response analysis can be performed.

8. SOURCE LISTING FOR PROGRAM SHAKE.

```
      PROGRAM SHAKE2(INPUT, OUTPUT, PUNCH)
C
C**************************************************************
C**************************************************************
C
C
C   THIS PROGRAM COMPUTES RESPONSE IN A HORIZONTALLY LAYERED SEMI-
C   INFINITE SYSTEM SUBJECTED TO VERTICALLY TRAVELLING SHEAR WAVES
C   THE METHOD IS BASED ON THE CONTINUOUS SOLUTION TO THE SHEAR WAVE
C   EQUATION
C
C
C   PROGRAMMED BY  PER B SCHNABEL RESEARCH ASSISTANT
C                  JOHN LYSMER    ASSOCIATE PROFESSOR
C
C                                 GEOTECHNICAL ENGINEERING
C                                 UNIVERSITY OF CALIFORNIA
C                                 BERKELEY
C
C
C   PROGRAM VERSION      SHAKE1   JANUARY 1972
C                        SHAKE2   APRIL 1972
C                                 JUNE 1972
C                                 CHANGE - OPTION 7 CORRECTED
C                                        - SUBROUTINES STEPS AND FFT
C                                          ADAPTED TO UNIVAC COMPUTERS
C                                 DECEMBER 1972
C                                 CHANGE - SUBROUTINES DRCTSP AND STRAIN
C
C
C
C**************************************************************
C**************************************************************
C
C
C
C   DEFINITIONS
C      INPUT MOTION       = MOTION READ IN FROM CARDS
C      OBJECT MOTION      = MOTION USED AS BASIS FOR COMPUTING NEW
C                           MOTIONS IN A SOIL PROFILE
C      COMPUTED MOTION    = MOTION COMPUTED ANYWHERE IN A GIVEN SOIL
C                           SOIL PROFILE FROM A GIVEN OBJECT MOTION
C      OPTION             = OPERATION TO BE PERFORMED ON GIVEN DATA,
C                           INITIALIZATION OR CHANGE OF DATA
C      QUIET ZONE         = ZONE CONTAINING THE TRAILING ZEROES IN
C                           THE INPUT MOTION
C      OUTCROP            = PLACE WHERE A SOIL SUBLAYER OR THE BASE
C                           ROCK REACHES A FREE SURFACE
C      OUTCROP MOTION     = MOTION AT AN OUTCROP OF ROCK OR SOIL SUBLAYER
C
C**************************************************************
C
C
C   FIRST CARD  FORMAT(I5,F10.0)
C        COL.   1- 5   MAX. NUMBER OF TERMS TO BE USED IN THE
C                      FOURIER TRANSFORMATION IN ANY OF THE PROBLEMS
C                      TO BE RUN
C        COL.   6-15   EARTH PRESSURE AT REST FOR SAND, USED ONLY
C                      FOR COMPUTING SHEAR MODULUS FOR SAND. IF
C                      BLANK THE VALUE IS SET TO .45
C
C   AFTER THIS FIRST CARD FOLLOWS SWITCH FOR OPTION TO BE PERFORMED. THE
C   AVAILABLE OPTIONS ARE LISTED BELOW. THE OPTIONS CAN BE EXECUTED AND
C   REPEATED IN ANY LOGICAL ORDER.
C
C
C   SECOND CARD AND CARD PRECEEDING EVERY OPTION, FORMAT(I5)
C          COL.   1- 5   SWITCH
C
C          SWITCH =  0    STOP, NO MORE DATA
C                    1    READ INPUT MOTION, TRANSFER TO FREQUENCY
C                         DOMAIN AND SET AS NEW OBJECT MOTION
C                    2    READ NEW SOIL PROFILE
C                    3    READ WHERE IN THE SOIL PROFILE THE OBJECT
C                         MOTION IS GIVEN
C                    4    OBTAIN STRAIN COMPATIBLE SOIL PROPERTIES
C                    5    COMPUTE NEW MOTIONS  PRINT OR PUNCH RESULTS
C                    6    PRINT AND/OR PUNCH TIME HISTORY OF OBJECT
C                         MOTION
C                    7    CHANGE PARAMETERS OF OBJECT MOTION OR
C                         SET A COMPUTED MOTION AS OBJECT MOTION
C                    8    READ SOIL PROPERTY/STRAIN-RELATIONS
C                    9    COMPUTE RESPONSE SPECTRA
C                   10    INCREASE TIMESTEP
C                   11    DECREASE TIMESTEP
C                   12    PLOT FOURIER SPECTRUM OF OBJECT MOTION
C                   13    PLOT FOURIER SPECTRUM OF COMPUTED MOTION
C                   14    PLOT TIME HISTORY OF OBJECT MOTION
C                         USE OPTION 7 FIRST FOR PLOT OF COMPUTED
C                         MOTION
C                   15    COMPUTE AMPLIFICATION FACTORS
C                   16    COMPUTE STRESS OR STRAIN HISTORY
C
C**************************************************************
C
C   DATA CARDS FOR THE DIFFERENT OPTIONS
C
C
C   1 READ INPUT MOTION
C      1 CARD (2I5, F10.0, 5A6)
C          COL.   1- 5   NUMBER OF VALUES TO BE READ
C          COL.   6-10   NUMBER OF VALUES TO BE USED IN FOURIER
C                        TRANSFORM  MUST BE A POWER OF 2
C          COL.  11-20   TIMESTEP BETWEEN EACH VALUE (SEC.)
C          COL.  21-50   IDENTIFICATION OF EARTHQUAKE
C
C      2 CARD  (3F10.0)
C          COL.   1-10   MULTIPLICATION FACTOR FOR ACC. VALUES
C                        USED ONLY IF COL. 11-20 IS 0.
C          COL.  11-20   SPECIFIED MAX. ACCELERATION
C          COL.  21-30   MAX. FREQUENCY TO BE USED IN FOURIER
C                        TRANSFORM (C/SEC.)
C
C      3 AND CONSEC. CARDS  (8F9.0, I8)
C          COL.   1-72    8 ACCELERATION VALUES
C          COL.  73-80    CARD NUMBER. CARDS MUST BE IN SEQUENCE
C
C
C   2 READ DATA FOR NEW SOIL PROFILE
C      1 CARD (2I5, 6A6)
C          COL.   1- 5   SOIL PROFILE NUMBER. OPTIONAL
C          COL.   6-10   TOTAL NUMBER OF SOIL LAYER INFORMATION CARDS
C                        TO BE READ INCLUDING CARD FOR HALFSPACE
C
```

```
C          COL. 11-15   NUMBER OF FIRST SUBMERGED SUBLAYER
C          COL. 16-92   SOIL PROFILE IDENTIFICATION
C
C     2 AND CONSEC. CARDS - SOIL LAYER INFORMATION CARDS
C       ONE CARD FOR EACH LAYER INCLUDING HALFSPACE (2I5, 6F10.0, F5.0)
C          COL.  1- 5   LAYER NUMBER
C                       LAYERS MUST BE IN SEQUENCE WITH SURFACE LAYER
C                       AS NUMBER 1
C          COL.     10  SOIL TYPE
C                         1 - CLAY  G = K*(UNDR. SHEAR STRENGTH)
C                         2 - SAND  G = K*(MEAN EFF. STRESS)**1/2
C                         3 - ROCK  G = K*(SHEAR MOD. AT LOW STRAINS)
C                         4 - SAND  G = K*(MAX. EFF. STRESS)**1/3
C                       WHERE K IS GIVEN THROUGH OPTION 8
C          COL. 11-15   NUMBER OF SUBLAYERS. THE LAYER WILL BE
C                       DIVIDED INTO SUBLAYERS OF EQUAL THICKNESS
C                       MAXIMUM TOTAL NUMBER OF SUBLAYERS FOR WHOLE
C                       PROFILE IS 19
C          COL. 16-25   THICKNESS OF LAYER (FT.)
C          COL. 26-35   SHEAR MODULUS (KIPS/SQ.FT.)
C                       NOT NECCESSARY IF SHEAR VEL. IS GIVEN
C          COL. 36-45   CRITICAL DAMPING RATIO
C          COL. 46-55   UNIT WEIGTH (KIPS/CUB.FT.)
C          COL. 56-65   SHEAR VELOCITY (FT./SEC.)
C                       NOT NECCESSARY IF SHEAR MOD. IS GIVEN
C          COL. 66-75   FACTOR FOR SHEAR MODULUS
C                       CLAY - UNDR. SHEAR STRENGTH (KIPS/SQ.FT.)
C                       SAND - FACTOR ON AVERAGE CURVE
C                       ROCK - WAVE VELOCITY IN 1000FT/SEC.
C          COL. 76-80   FACTOR FOR DAMPING
C
C                       FOR HALFSPACE ONLY COL. 1- 5, 26-35 OR 56-65,
C                       AND 46-55 ARE NECESSARY
C
C
C     3 SUBLAYER WHERE OBJECT MOTION IS GIVEN
C        1 CARD (2I5)
C          COL.  1- 5   SUBLAYER NUMBER
C          COL.     10  TYPE OF MOTION 0 - OUTCROPPING ROCK OR
C                                          OUTCROPPING SOIL SUBLAYER
C                                      1 - BASE ROCK OR SOIL SUBLAYER
C                                          WITHIN PROFILE
C
C
C     4 OBTAIN SOIL PROPERTIES COMPATIBLE WITH EFFECTIVE STRAINS
C        1 CARD (2I5, 7F10.0)
C          COL.      5  SET EQ TO 1 FOR PUNCHED OUTPUT OF NEW SET
C                       OF SOIL DATA CARDS
C          COL.  6-10   MAXIMUM NUMBER OF ITERATIONS
C          COL. 11-20   MAX ERROR IN PRCNT.  ITERATION  STOPS WHEN
C                       ERROR IS LESS OR WHEN MAX. NUMBER OF
C                       ITERATIONS ARE REACHED
C          COL. 21-30   RATIO EFFECTIVE STRAIN/MAX. STRAIN
C
C
C     5 COMPUTE NEW MOTIONS
C        1 CARD (15I5)
C          COL.  1-75   ARRAY WITH NUMBER OF SUBLAYERS WHERE MOTION
C                       IS TO BE COMPUTED. MOTION IS COMPUTED AT THE
C                       TOP OF THE SUBLAYER
C
C        2 CARD (15I5)
C          COL.  1-75   ARRAY WITH TYPE OF ABOVE SUBLAYERS
C                                     0 - OUTCROPPING SUBLAYER
C                                     1 - SUBLAYER WITHIN PROFILE
C
C        3 CARD(15I5)
C          COL.  1-75   ARRAY WITH MODE OF OUTPUT
C                       0 - TABLE OF MAX. ACCELERATIONS ONLY
C                       1 - PUNCHED TIME HISTORY IN ADDITION TO TABLE
C
C
C     6 PRINT AND/OR PUNCH TIME HISTORY OF OBJECT MOTION
C        1 CARD (2I5)
C          COL.  5      0 - MAX. ACCELERATION ONLY
C                       1 - PUNCHED OUTPUT OF TIME HISTORY
C                       2 - PUNCHED AND PRINTED OUTPUT OF TIME HISTORY
C
C
C
C     7 CHANGE OBJECT MOTION
C        1 CARD  (2I5, F10.0)
C          COL.  1- 5   SUBLAYER NUMBER
C                       THE ACCELERATIONS AT THE TOP OF THE SUBLAYER
C                       WILL BE SET AS NEW OBJECT MOTION
C                       SET = 0 IF ORIGINAL OBJECT MOTION IS KEPT
C          COL.  6-10   TYPE OF MOTION  0 - OUTCROPPING SUBLAYER
C                                       1 - WITHIN PROFILE
C          COL. 11-20   MULTIPLICATION FACTOR FOR MOTION
C          COL. 21-30   NEW TIMESTEP (SEC.)
C
C     8 READ RELATION BETWEEN SOIL PROPERTIES AND STRAIN
C        1 CARD (3I5, F10.0)
C          COL.  1- 5   NUMBER OF DIFFERENT SOIL OR ROCK TYPES TO BE
C                       READ  MAX. 4
C          COL.     10  SET EQ. TO 1 FOR PLOT OF PROPERTY STRAIN
C                       RELATION
C          COL. 11-15   NUMBER OF VALUES IN EACH LOG10 FOR
C                       PLOTTING OF PROPERTY/STRAIN RELATION IN
C                       SEMILOG PLOT
C          COL. 16-25   SCALE FOR PLOTTING (MAX. ORDINATE VALUE)
C
C        NEXT FOLLOWS TWO SETS OF CARDS FOR EACH SOIL/ROCK TYPE
C        FIRST SET  -  RELATION STRAIN-SHEAR MODULUS
C        1 CARD (I5,F5.0, 12A6)
C          COL.  1- 5   NUMBER OF STRAIN VALUES FOR WHICH SHEAR
C                       MODULUS PARAMETERS ARE GIVEN. MAX.20
C          COL.  6-10   MULTIPLICATION FACTOR FOR SHEAR MODULUS
C                       USED FOR PLOTTING ONLY
C          COL. 11-76   TITLE FOR SOIL TYPE
C
C        2 CARD AND CONSECUTIVE CARDS (8F10.0)
C             STRAIN VALUES. 8 VALUES PER CARD (PERCENT)
C
C        CONSECUTIVE CARDS (8F10.0)
C             VALUES OF MODULUS PARAMETER CORRESPONDING TO     STRAIN
C             VALUES GIVEN. 8 VALUES PER CARD.
C
C        SECOND SET - RELATION STRAIN-DAMPING
C             CARDS AS FOR FIRST SET BUT WITH VALUES OF CRITICAL
C             DAMPING RATIO INSTEAD OF MODULUS PARAMETER VALUES
C
C
C     9 RESPONSE SPECTRUM
```

```
C     1 CARD (I5)
C         COL.  1- 5   SUBLAYER NUMBER
C                      SET = 0 IF OBJECT MOTION
C         COL.     10  TYPE OF SUBLAYER  0 - OUTCROPPING
C                                        1 - WITHIN
C
C     2 CARD (4I5)
C         COL.      5  TOTAL NUMBER OF DAMPING VALUES MAX. 6
C         COL.     10  SET EQ. TO 1 FOR PUNCHED OUTPUT
C         COL.     15  SWITCH  0 - PLOT AND/OR PUNCH VEL. SPECTRUM
C                              1 - PLOT AND/OR PUNCH ACC. SPECTRUM
C                              2 - PLOT AND/OR PUNCH ACC. AND VEL. SPECTRA
C         COL.     20  SWITCH FOR PLOTTING
C                           0 - STORE SPECTRA FOR LATER PLOTTING
C                               MAX. 9
C                           1 - PLOT ALL SPECTRA COMPUTED AND
C                               STORED SINCE LAST PLOTTING
C         COL.     25  SWITCH FOR PERIODS TO BE USED. FIRST PERIOD
C                      IS .001 SEC.
C                      0 - 9 STEPS FROM  .1 TO 1.
C                          9 STEPS FROM 1.  TO 2.
C                          4 STEPS FROM 2.  TO 4.
C                      1 -20 STEPS FROM  .1 TO 1.
C                         20 STEPS FROM 1.  TO 2.
C                          8 STEPS FROM 2.  TO 4.
C                      2 -50 STEPS FROM  .05 TO 1.
C                         50 STEPS FROM 1.  TO 2.
C                         50 STEPS FROM 2.  TO 5.
C                      3 -LOGARITHMIC INCREMENTS
C                         20 STEPS IN EACH LOG. UNIT FROM .1 TO 5.
C                      4 -LOGARITHMIC INCREMENTS
C                         25 STEPS IN EACH LOG. UNIT FROM .05 TO 10.
C
C     3 CARD (6F10.0)
C         VALUES OF CRITICAL DAMPING RATIO   MAX. 6 VALUES
C
C
C  10 INCREASE TIMESTEP
C       1 CARD (I5)
C         COL.  1- 5   FACTOR FOR INCREASING TIMESTEP
C                      MUST BE A POWER OF 2
C
C  11 DECREASE TIMESTEP
C       1 CARD (I5)
C         COL.  1- 5   FACTOR FOR DECREASING TIMESTEP
C                      MUST BE A POWER OF 2
C
C  12 PLOT FOURIER SPECTRUM OF OBJECT MOTION
C       1 CARD (3I5)
C         COL.      5  SWITCH FOR PLOTTING
C                           0 - STORE SPECTRUM FOR LATER PLOTTING
C                               MAX. 2 SPECTRA PLOTTED TOGETHER
C                           1 - PLOT ALL SPECTRA STORED SINCE
C                               LAST PLOTTING
C         COL.  6-10   NUMBER OF TIMES SPECTRUM IS TO BE SMOOTHENED
C         COL. 11-15   NUMBER OF FREQUENCIES TO BE PLOTTED MAX. 2049
C
C  13 PLOT FOURIER SPECTRA OF COMPUTED MOTION
C       1 CARD (5I5)
C         COL.  1- 5   SUBLAYER NUMBER FOR FIRST COMPUTED MOTION
C         COL.     10  TYPE OF ABOVE SUBLAYER    0 - OUTCROP
C                                                1 - WITHIN
C         COL.     15  SWITCH FOR PLOTTING
C                           0 - STORE SPECTRUM FOR LATER PLOTTING
C                               MAX. 2 SPECTRA PLOTTED TOGETHER
C                           1 - PLOT ALL SPECTRA STORED SINCE
C                               LAST PLOTTING
C         COL. 16-20   NUMBER OF TIMES SPECTRA ARE TO BE SMOOTHENED
C         COL. 21-25   NUMBER OF FREQUENCIES TO BE PLOTTED MAX. 2049
C
C     2 CARD (5I5)
C         AS FIRST CARD FOR SECOND MOTION. BLANK IF ONLY ONE MOTION
C
C
C  14 PLOT TIME- HISTORY OF OBJECT MOTION
C       1 CARD (2I5)
C         COL.  1- 5   STEPS IN PLOTTING
C                      1 - PLOT EACH VALUE
C                      2 - PLOT EVERY SECOND VALUE
C                      AND SO ON
C         COL.  6-10   NUMBER OF VALUES TO BE PLOTTED. MAX. 2000
C                      IF BLANK WHOLE RECORD IS PLOTTED
C
C
C  15 COMPUTE AMPLIFICATION FUNCTION
C       1 CARD (I5,I5,I5,I5,I5,F5.0, A6)
C         COL.  1- 5   SUBLAYER NUMBER FROM WHICH AMPLIFICATION
C                      FACTORS IS COMPUTED
C         COL.     10  TYPE OF ABOVE SUBLAYER    0 - OUTCROP
C                                                1 - WITHIN
C         COL. 11-15   SUBLAYER NUMBER TO WHICH AMPLIFICATION
C                      FACTORS IS COMPUTED
C         COL.     20  TYPE OF ABOVE SUBLAYER    0 - OUTCROP
C                                                1 - WITHIN
C         COL.     25  IF   0 - OUTPUT MAX AMP. FACTOR AND FREQUENCY
C                               STORE FUNCTION FOR LATER PLOTTING
C                               MAXIMUM 4 CURVES CAN BE STORED
C                           1 - PLOT AMPLIFICATION FUNCTION TOGETHER
C                               WITH ALL FUNCTIONS STORED
C         COL. 26-30   FREQUENCY STEPS IN COMPUTING AMPLIFICATION
C                      FUNCTION. THE FIRST 200 FREQ. ARE COMPUTED
C         COL. 35-70   IDENTIFIER
C
C  16 COMPUTE STRAIN OR STRESS  TIME HISTORY
C       2 CARD (4I5,2I5,F10.0,3A6)
C         COL.  1- 5   NUMBER OF SUBLAYER WHERE RESPONSE IS TO BE
C                      COMPUTED AT MIDDLE OF LAYER
C         COL.     10  RESPONSE TYPE
C                        0 - STRAIN HISTORY
C                        1 - STRESS HISTORY
C         COL.     15  SET EQUAL TO 1 IF PUNCHED OUTPUT IS WANTED
C         COL.     20  SET EQUAL TO 1 FOR PLOTTING
C         COL. 21-25   NUMBER OF VALUES TO BE PLOTTED. MAX. 2049
C         COL. 26-35   SCALE FOR PLOTTING - I.E. MAX VAL. OF COORDINATE
C                      IF 0. LARGEST VALUE IS SET AS MAX. ORD. VALUE
C         COL. 37-49   IDENTIFICATION
C
C     2 CARD           AS CARD 1 FOR 2ND RESPONSE.
C                      BLANK IF ONLY ONE RESPONSE IS WANTED. FOR 2 RESP
C
C*****************************************************************
```

58

```
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C
      COMMON [illegible]
      COMMON /[illegible]/ [illegible], GT, [illegible]
C
      [illegible] = .0026
      GT = 32.2
      READ [illegible], [illegible], [illegible]
      [illegible] = [illegible] + 9
      [illegible] = [illegible] + [illegible] + 4[illegible]
      [illegible] = [illegible] + [illegible]
      [illegible] = [illegible] + [illegible] + 1
      [illegible] = [illegible] + [illegible] + 1
      IF ([illegible] .LT. .[illegible]) [illegible] = .4[illegible]
      PRINT 2000, [illegible], [illegible], [illegible]
      CALL [illegible]([illegible], [illegible], [illegible], [illegible], [illegible])
      STOP
 1000 FORMAT(I5, F10.0)
 2000 FORMAT(// 45H  [illegible]. NUMBER OF [illegible] IN POSITION [illegible] =   I10/
     1          45H  NECESSARY LENGTH OF [illegible] COMMON [illegible]      =   I10/
     2          45H  EARTH PRESSURE AT REST FOR SAND              =  F10.3)
      END
```

```
      SUBROUTINE [illegible]([illegible],[illegible],[illegible],[illegible],[illegible])
C
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     THIS ROUTINE CALLS THE DIFFERENT SEQUENCES OF OPERATION. 1[illegible] DIFFERENT
C     OPERATIONS CAN BE PERFORMED AS LISTED BELOW.
C
C        OPERATION                                               SUBROUTINES
C
C        1  READ INPUT MOTION                                    [illegible]
C                                                                [illegible]
C                                                                [illegible]
C                                                                [illegible]
C                                                                [illegible]
C        2  READ SOIL PROFILE                                    SOILIN
C                                                                [illegible]
C
C        3  READ LAYER WHERE OBJECT MOTION IS GIVEN
C
C        4  ITERATE ON SOIL PROPERTIES                           [illegible]
C                                                                [illegible]
C                                                                [illegible]
C                                                                [illegible]
C                                                                [illegible]
C                                                                [illegible]
C                                                                [illegible]
C
C        5  COMPUTE MOTION IN NEW LAYER AND GIVE OUTPUT          [illegible]
C                                                                [illegible]
C                                                                [illegible]
C                                                                [illegible]
C                                                                [illegible]
C                                                                [illegible]
C
C        6  PRINT OR PUNCH OBJECT MOTION                         [illegible]
C                                                                [illegible]
C                                                                [illegible]
C                                                                [illegible]
C                                                                [illegible]
C
C        7  CHANGE OBJECT MOTION                                 [illegible]
C
C        8  READ RELATION BETWEEN STRAIN AND SOIL PROPERTY.      [illegible]
C                                                                [illegible]
C                                                                [illegible]
C                                                                PLOT
C
C                                                                [illegible]
C        9  COMPUTE RESPONSE SPECTRA                             RESP
C                                                                [illegible]
C                                                                [illegible]
C                                                                [illegible]
C                                                                [illegible]
C                                                                [illegible]
C                                                                [illegible]
C                                                                PLOT
C
C       10  REDUCE NO. OF VALUES AND INCREASE TIMESTEP           [illegible]
C
```

```
C      11 INCREASE NO. OF VALUES AND DECREASE TIMESTEP    INCR
C
C      12 PLOT FOURIER SPECTRUM OF OBJECT MOTION           PLOT
C
C      13 PLOT FOURIER SPECTRA OF COMPUTED MOTION          PLOT
C
C      14 PLOT TIME HISTORY OF OBJECT MOTION
C                                                         QPPT
C                                                         QPSH
C                                                         PLOT
C
C      15 COMPUTE AND PLOT AMPLIFICATIONFUNCTION          AMP
C                                                         PLOT
C
C      16 COMPUTE STRAIN/STRESS-HISTORY                   STRAIN
C                                                         PLOT
C                                                         PPT
C                                                         QPPT
C                                                         QPSH
C
C*****************************************************************
C
C  CODED BY PER B. SCHNABEL  1970/1971/1972
C
C*****************************************************************
C
      INTEGER TITLE,TP
      COMPLEX A, AX
      COMPLEX G, V, PLUS, MINUS
      DIMENSION ABSTS(10), ABSPR(10),ABSCL(10)
      DIMENSION LL(3), LT(3),LTSH(3)
      DIMENSION LLL(2), LLGS(2),LLPCH(2),LLPL(2),SR(2),LNN(2)
      DIMENSION X(300),AX(3,270),AA(2,550),S(70),[illegible](70)
      DIMENSION LLS(15), LTS(15), LPS(15),LP(5)
      DIMENSION IDAMP(9,11)
      COMMON /EQ/ [illegible],AA2,TITLE(9),DT, MA , MMA, QP,QR
      COMMON /SOILA/ [illegible](6),DL(23),GL(23),FACT(20),H(20),R(20),BF(20)
      COMMON /SOILB/ FAC(20), WL(20), TP(20), DEPTH(20), WEIGHT(20)
      COMMON /SOILC/ [illegible],[illegible]
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
      COMMON /CCG/ [illegible](9,11), T(2049)
C
      DATA [illegible] /6H      /
      DATA (ABSTS(I),I=1,10)/6H TIME  ,6H[illegible] SEC ,6H[illegible]  ,7H[illegible]    /
      DATA (ABSCL(I),I=1,10)/6H  CYCL ,6HES/SEC   , 9H[illegible]     /
      DATA (ABSPR(I), I=1,10)/6H PERIO, 6HD IN S, 6HEC.   , 7H[illegible]     /
C
C
C**********
C
      DO 102 I = 1,3
      LL(I) = 3
  102 LT(I) = 0
      DO 109 L = 1,9
      DO 109 I = 1,11
      [illegible](L,I) = [illegible]
  139 IDAMP(L,I) = [illegible]
      [illegible] = 0
      [illegible] = 0
      [illegible] = 3
      [illegible] = 1
C
C**********
  101 READ 1000, KK
      IF (KK .EQ. 0) STOP
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16), KK
C
C**********
    1 PRINT 1002,KK
      CALL EARTHQ(X,AX,AA, S, INV)
      NSW = 0
      GO TO 101
C
C**********
    2 PRINT 2002,KK
      CALL SOIL(NSW)
      NSW = 1
C
C   FIND FUNDAMENTAL PERIOD OF DEPOSIT FROM AVERAGE SHEAR WAVE VELOCITY
C   AND FROM THE PERIOD WHICH GIVE MAXIMUM AMPLIFICATION
      SH = 0.
      N = NL + 1
      SHV = 0.
      DO 21 I = 1,NL
      SH = SH + H(I)
   21 SHV = SHV + H(I)*SQRT(G(I)/R(I))
      VSAV = SHV/SH
      TT = 4.*SH/VSAV
      PRINT 4000, TT, VSAV
      DFA = .5/TT
      CALL AMP([illegible])
      GO TO 101
C
C**********
    3 PRINT 3330, KK
      READ 7000, IN, INT
      IF (INT .EQ. 3) PRINT 3331,IN
      IF (INT .NE. 0) PRINT 3000, IN
      GO TO 101
C
C
C**********
    4 PRINT 4007,KK
      READ 4000,KS,ITMAX,ERR,PRMUL
      PRINT 4331, ITMAX,ERR,PRMUL
      LL(2) = 1
      LT(1) = 0
      DO 41 L = 1,ITMAX
      IF (IN.EQ.1) GO TO 412
      CALL MOTION(IN, INT, LL, LT, X,AX)
  412 CALL STRT(L, NL, [illegible],PRMUL,X,AX,AA,S,INV)
      IF (EGMAX.LT.ERR) GO TO 411
   41 CONTINUE
C
C   FIND FUNDAMENTAL PERIOD OF DEPOSIT FROM AVERAGE SHEAR WAVE VELOCITY
C   AND FROM THE PERIOD WHICH GIVE MAXIMUM AMPLIFICATION
  411 SH = 0.
      N = NL + 1
      SHV = 0.
      DO 43 I = 1,NL
      SH = SH + H(I)
   43 SHV = SHV + H(I)*SQRT(G(I)/R(I))
      VSAV = SHV/SH
      TT = 4.*SH/VSAV
```

```
      PRINT 4034, TT, YEAR
      DT = .01/TT
      CALL EXPINT(N,1,1,0,0,1000,Y, 9, DT)
      IF (NS .EQ. 9)  GO TO 101
C
C   PUNCH NEW SET OF SOILDEPOSIT DATA CARD WITH NEW PROPERTIES
      PUNCH 4003, NSOIL, N, NML, IDNT, (TITLE(I),I=1,4)
      DO 42 I = 1,N
   42 PUNCH 4334,I,TP(I), H(I), GL(I), DL(I), WL(I), PAC(I) ,DP(I)
      PUNCH 4007,N,GL(N),DL(N),WL(N)
      GO TO 101
C
C * * * * * * * * * *
    9 PRINT 5331,NN
      READ 1000, (LL9(L),L=1,19)
      READ 1000, (LT9(L),L=1,19)
      READ 1000, (LP9(L),L=1,19)
      PRINT  5002, TITLE, IDNT
      I = 3
      DO 91 LOOP = 1,5
      DO 911 L = 1,3
      I = I + 1
      LL(L) = LL9(I)
      LT(L) = LT9(I)
      LP(L) = LP9(I)
      IF (LL(I).EQ.0) GO TO 101
  911 CONTINUE
      CALL ACTION(N,IN, INT, LL, LT, X,AX)
      DO 91  L = 1,3
      N = LL(L)
      K = L
      IF (N.EQ.0) GO TO 101
      IF (N.LE.N1)  DPTH = DEPTH(N) - H(N)/2.
      IF (N.GT.N1)  DPTH = DEPTH(N-1) + H(N-1)/2.
      CALL STPRINT(DPTH,K,LP(L),LL(L),LT(L),X,AX,AA,S,INV)
   91 CONTINUE
      GO TO 101
C
C * * * * * * * * * *
    6 PRINT 6002,NN
      READ 1000, K7
      LS = 0
      LN = IN
      IF (K7.EQ.3)  PRINT 6333, LN
      IF (K7.EQ.1)  PRINT 6001, LN
   62 CALL STPRINT(DPTH,LS,K7,LN,INT     ,X,AX,AA,S,INV)
      GO TO 101
C
C * * * * * * * * * *
    7 PRINT 7002,NN
      READ 7001, LL1,LT1,DP,DTNEW
      IF (DTNEW.LT..333) DTNEW=DT
      IF (LL1  .EQ.0) GO TO 71
C
C   CHECK IF MOTION IN SUBLAYER LL1 IS IN ARES
      DO 72 I = 1,3
      IF (LL1.NE.LL(I) .OR. LT1.NE.LT(I)) GO TO 72
      L = I
      GO TO 720
   72 CONTINUE
      LL(1) = LL1
      LT(1) = LT1
      K = 1
      CALL ACTION(N,IN, INT, LL, LT, X,AX)
  720 DO 73 I = 1,NPJLD
   73 X(I) = AX(L,I)*DP
      NEW = LL(L)
      INT = LT(L)
      GO TO 75
   71 DO 74 I = 1,NPJLD
   74 X(I) = X(I)*DP
      NEW = IN
   75 IN = NEW
      PRINT 7030, NEW , DP,DT, DTNEW
      DT = DTNEW
      DF = 1./(TMAX*DT)
      GO TO 101
C
C * * * * * * * * * *
    8 PRINT 8001,NN
      CALL CO
      GO TO 101
C
C * * * * * * * * * *
    0 PRINT 9001,NN
      READ 1000, LL1, LT1
      IF (LL1.NE.0) GO TO 171
      PRINT 9001
      LS = 0
      LN = IN
      GO TO 179
  171 DO 173 I = 1,3
      IF (LL1.NE.LL(I) .OR. LT[illegible].LT(I)) GO TO 170
      LS = I
      GO TO 172
  170 CONTINUE
      LS = 1
      LL(1) = LL1
      LT(1) = LT1
      CALL ACTION(N,IN, INT, LL, LT, X,AX)
  172 LN = LL(LS)
      PRINT 9303,LN
  179 CALL RESP(LL,LN,LS,NN,X,AX,AA,S,INV)
      GO TO 101
C
C * * * * * * * * * *
   10 PRINT 1003,NN
      READ 1000, IPR
      CALL REDUCE(IPR,X,AX,LL)
      GO TO 101
C
C * * * * * * * * * *
   11 PRINT 1101,NN
      READ 1000, IPR
      CALL INCR(IPR,X,AX,LL)
      GO TO 101
C
C * * * * * * * * * *
   12 PRINT 1203,NN
      READ 1333, KI, YSA, N
      IF (INT     .EQ. 0) PRINT 1201, IN
      IF (INT     .EQ. 1) PRINT 1232, IN
      NP = NP + 1
      IF (N.LE.0)  N= NPJLD - [illegible]
```

```
      IF (N.GT.2049)   N=2049
      DO 120 I = 1,N
  120 ARTMP(I) = CABS(Z(I))
      DO 121 I = 1,5
  121 IDTMP(I) = TITLE(I)
      DO 126 I = 6,11
  126 IDTMP(I) = IBLANK
      IF (NSM.EQ.2) GO TO 127
      M = N-1
      DO 124 LOOP = 1,NSM
      ARTMP(1) = (3.*ARTMP(1) + ARTMP(2))/4.
      ARTMP(N) = (3.*ARTMP(N) + ARTMP(N-1))/4.
      DO 124 I = 2,M
  124 ARTMP(I) = (ARTMP(I-1) + 2.*ARTMP(I) + ARTMP(I+1))/4.
  127 IF (K1.NE.1) GO TO 101
      DO 122 I = 1,N
      T(I) = FLOAT(I-1)*DP
  122 CONTINUE
      PRINT 1200
      CALL PLOTIMP,  N,T,AA,AXSCL,10.0,.2,NP)
      NP = 3
      GO TO 101
C
C * * * * * * * * * *
   17 PRINT 1500,KK
      DO 103 I = 1,2
  100 READ 1000, LL(I), LT(I), LP(I), LNDW(I), LLL(I)
      CALL ACTION(NS, IN, INF, LL, LT, X, AX)
      DO 104 L = 1,2
      IF (LLL(L).EQ.0) GO TO 101
      IF (LT(L).EQ.3) PRINT 1201,LL(L)
      IF (LT(L).EQ.1) PRINT 1202,LL(L)
      N = LLL(L)
      IF (N.LE.0)   N = NFOLD - 1
      IF (N.GT.2049)   N = 2049
      NP = NP + 1
      IF (NP.LE.2)  GO TO 102
      PRINT 1000
 1000 FORMAT(//  24H TOO MANY ARRAYS STORED   /)
      GO TO 101
  102 DO 190 I = 1,5
  190 IDTMP(I) = TITLE(I)
      DO 107 I = 6,11
  107 IDTMP(I) = IDW(I-5)
      DO 109 I = 1,N
  109 ARTMP(I) = CABS(ARR(L,I))
      NSM = LNSW(L)
      IF (NSM.EQ.0) GO TO 101
      M = N-1
      DO 106 LOOP = 1,NSM
      ARTMP(1) = (3.*ARTMP(1) + ARTMP(2))/4.
      ARTMP(N) = (3.*ARTMP(N) + ARTMP(N-1))/4.
      DO 106 I = 2,M
  106 ARTMP(I) = (ARTMP(I-1) + 2.*ARTMP(I) + ARTMP(I+1))/4.
      IF (LP(L).EQ.0) GO TO 104
  101 DO 103 I = 1,N
  103 T(I) = DP*FLOAT(I-1)
      PRINT 1200
      CALL PLOTIMP,  N,T,AA,AXSCL,10.0,.2,NP)
      NP = 0
  104 CONTINUE
      GO TO 101
C
C * * * * * * * * * *
   18 PRINT 1400,KK
      READ 1003, NSKIP, NN, NSW
      NP = NP + 1
      CALL RFSORT(A,NN,INV,S,IFERR)
      IF (NN.LE.0)  NN = NNB/NSKIP
      IF (NN.GT.2049)  NN = 2049
      ND =  NN*NSKIP
      N = 0
      DO 130 I=1, ND, NSKIP
      N = N + 1
      T(N) = FLOAT(I-1)*DT
  130 CONTINUE
      N = 0
      M = NN/2
      DO 193 I = 1,M
      N = N + 1
      ARTMP(N) = REAL(X(I))
      N = N + 1
      ARTMP(N) = AIMAG(X(I))
  193 CONTINUE
      IF  (NSKIP.EQ.1) GO TO 199
      N = 0
      DO 194 I = 1,ND ,NSKIP
      N = N + 1
      ARTMP(N) = ARTMP(I)
  194 CONTINUE
  199 CALL RFFTI(A,NN,INV,S,IFERR)
      DO 191 I = 1,5
  191 IDTMP(I) = TITLE(I)
      DO 192 I = 6,11
      IDTMP(I) = IDW(I-5)
      IF (NSW.EQ.0)  IDTMP(I)  = IBLANK
  192 CONTINUE
      IF (NSW.EQ.1) GO TO 101
      CALL PLOTIMP, N, T, AA, AXSIS, 10. 3.. 2. NP)
      NP = 0
      GO TO 101
C
C * * * * * * * * * *
   19 PRINT 1927,KK
      READ 1400, LIN, LINT ,LOUT,LOTP,KP,DFS,(IDAMPING(I),I=1,8)
      PRINT 1401, LIN,LOUT
      IF  (LOTP.EQ.0) PRINT 1403
      IF  (LINT.EQ.0) PRINT 1402
      CALL ARTIME, LIN, LINT, LOUT, LOTP, KP, IDAMP,NA, DFS)
      GO TO 101
C
C * * * * * * * * * *
   16 PRINT 1601,KK
      DO 191 L = 1,2
      READ 1900, LLL(L),LLCS(L),LLPCH(L),LLPL(L),LNW(L),S(L),
     1(IDW(L,I),I=7,11)
      IF (LLL(L).GT.0) PRINT 1901,LLL(L),S(L),(IDW(L,I),I=7,11)
  191 CONTINUE
      DO 192 L = 1,3
  192 LT(L) = 0
      LL(1) = 0
      LL(2) = 0
      LL(3) = 1
      CALL ACTION(NS, IN, INF, LL, LT, X, AX)
```

```
      CALL [illegible]
      DO 193 I = 1,3
  1[illegible] LLIII = 0
      GO TO 101
C
C * * * * * * * * * *
C
 1000 FORMAT(1H1)
 1002 FORMAT(1H0,[illegible]       OPTION  I3,
     1 [illegible]  ***  READ INPUT MOTION                                   ///
 [illegible] FORMAT(1H0,[illegible]     OPTION  I3,
     1 [illegible]  ***  READ SOIL PROFILE                                   ///
 [illegible] FORMAT(///32H  OBJECT MOTION IN LAYER NUMBER    I3//)
 [illegible] FORMAT(///[illegible]  OBJECT MOTION IN LAYER NUMBER I3,12H OUTCROPPING //)
 [illegible] FORMAT(1H0,[illegible]     OPTION  I3,
     1 [illegible]  ***  [illegible] OBJECT MOTION IS GIVEN                  /
 [illegible] FORMAT( [illegible])
 [illegible] FORMAT(
     1 [illegible] NUMBER OF ITERATIONS                          =    [illegible]
     1 [illegible] ERROR IN PERCENT                              = [illegible]
     1 [illegible] FACTOR FOR EFFECTIVE STRAIN IN TIME DOMAIN    = [illegible]//)
 [illegible] FORMAT([illegible])
 [illegible] FORMAT([illegible])
 [illegible] FORMAT([illegible])
 [illegible] FORMAT(//[illegible] PERIOD = [illegible] FROM AVERAGE SPECTRUM [illegible] = [illegible])
 [illegible] FORMAT(1H0,[illegible]     OPTION  I3,
     1 [illegible]  ***  OBTAIN STRAIN COMPATIBLE SOIL PROPERTIES             ///
 [illegible] FORMAT(1H0,[illegible]     OPTION  I3,
     1 [illegible]  ***  COMPUTE MOTION IN NEW SUBLAYERS                     ///
 [illegible] FORMAT([illegible]  EARTHQUAKE - [illegible]  SOIL DEPOSIT - [illegible]
     1[illegible]  [illegible]
     1 [illegible]
     1 [illegible]
     [illegible]
     [illegible]  ///
 [illegible] FORMAT([illegible]          ACCELERATION IN LAYER  [illegible]
 [illegible] FORMAT([illegible]                ACCELERATION IN LAYER  [illegible]
 [illegible] FORMAT(1H0,[illegible]     OPTION  I3,
     1 [illegible]  ***  [illegible] OBJECT MOTION                           ///
 [illegible] FORMAT([illegible]  [illegible] MOTION IN LAYER  I3,[illegible] OBJECT MOTION /
     1[illegible] FACTOR FOR NEW MOTION =  [illegible]
     [illegible] OF [illegible] FROM [illegible] TO [illegible] SEC.//)
 [illegible] FORMAT([illegible])
 [illegible] FORMAT(1H0,[illegible]     OPTION  I3,
     1 [illegible]  ***  [illegible] OBJECT MOTION                           /
 [illegible] FORMAT(1H0,[illegible]     OPTION  I3,
     1 [illegible]  ***  READ RELATION BETWEEN SOIL PROPERTIES AND STRAIN    ///
 [illegible] FORMAT([illegible]  COMPUTE RESPONSE SPECTRUM IN LAYER  I3//)
 [illegible] FORMAT(///[illegible] COMPUTE RESPONSE SPECTRUM OF OBJECT MOTION //)
 [illegible] FORMAT(1H0,[illegible]     OPTION  I3,
     1 [illegible]  ***  COMPUTE RESPONSE SPECTRUM                           /
 [illegible] FORMAT(1H0,[illegible]     OPTION  I3,
     1 [illegible]  ***  [illegible]                                         ///
 [illegible] FORMAT(1H0,[illegible]     OPTION  I3,
     1 [illegible]  ***  [illegible]                                         ///
 [illegible] FORMAT([illegible] PLOT OF [illegible] SPECTRA ///
 [illegible] FORMAT([illegible]  LAYER NUMBER I4, 12H OUTCROPPING ///
 [illegible] FORMAT([illegible]  LAYER NUMBER I4///
 [illegible] FORMAT(1H0,[illegible]     OPTION  I3,
     1 [illegible]  ***  PLOT OF [illegible] SPECTRUM OF OBJECT MOTION        ///
 [illegible] FORMAT(1H0,[illegible]     OPTION  I3,
     1 [illegible]  ***  PLOT [illegible] SPECTRUM OF COMPUTED MOTION         ///
```

```
 1400 FORMAT([illegible])
 1401 FORMAT([illegible]  AMPLIFICATION SPECTRUM BETWEEN LAYER I4, [illegible] AND [illegible]
 1402 FORMAT([illegible]  INPUT LAYER OUTCROPPING )
 1403 FORMAT([illegible]  OUTPUT LAYER OUTCROPPING )
 [illegible] FORMAT(1H0,[illegible]     OPTION  I3,
     1 [illegible]  ***  PLOT TIME HISTORY OF OBJECT MOTION                  ///
 1900 FORMAT([illegible])
 1901 FORMAT(//  [illegible]  COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF
     1 [illegible] LAYER  I[illegible] /[illegible]  SCALE FOR PLOTTING  [illegible]  [illegible] IDENTIFICATION
     2 [illegible] -    [illegible])
 1902 FORMAT(1H0,[illegible]     OPTION  I3,
     1 [illegible]  ***  COMPUTE AMPLIFICATION FUNCTION                      ///
 [illegible] FORMAT(1H0,[illegible]     OPTION  I3,
     1 [illegible]  ***  COMPUTE STRESS/STRAIN HISTORY                       ///
      END
```

```
      SUBROUTINE FORTAU(X,XR,XN,S,INV)
C
C*****************************************************************
C
C   THIS ROUTINE  READS THE MOTION IN THE TIME DOMAIN, ADDS TRAILING
C   ZEROS, SCALES THE VALUES, FIND MAXIMUM VALUE AND VARIOUS PARAMETERS
C   AND TRANSFER THE MOTION INTO THE FREQUENCY DOMAIN.
C
C   CODED BY PBS SEPT. 1970
C
C
C        X       = INPUT MOTION
C        XR      = TEMPORARY STORAGE OF X
C        TITLE   = IDENTIFICATION FOR MOTION
C        DT      = TIME STEP BETWEEN VALUES IN TIME DOMAIN
C        NV      = NUMBER OF ACC. VALUES TO BE READ
C        MA      = LENGTH OF MOTION INCLUDING TRAILING ZEROS
C        MMA     = LENGTH OF SIGNIFICANT PART OF MOTION
C        XF      = MULTIPLICATION FACTOR FOR ACCELERATION VALUES
C        DF      = FREQUENCY STEPS IN FREQ. DOMAIN
C
C*****************************************************************
C
      INTEGER TITLE
      COMPLEX X, XR
      DIMENSION XR(8)
      DIMENSION X(300),AR(3,270),AA(2,990),S(70),INV(70)
      COMMON /BD/ MFOLD,MA2,TITLE(9),DT, MA , MMA, DF, MX
C
      FEE = 0.70
      READ 1001, NV, NR, DT, TITLE
      READ 1003, XF,XMAX,FMAX
      IF (FMAX.LT. .001) FMAX = 1000.
      MA2=2
    2 IF(MA2.GT.MA) GO TO 3
      MA2=MA2*2
      GO TO 2
    3 MA=MA2
      PRINT 2312, TITLE, NV, DT, MA
      MMA = NV + NV/10
      IF (MMA.GT.MA) MMA=MA
      MA2 = MA + 2
      MFOLD = MA2/2
      MFOLD = MFOLD + 1
      DF = 1./(MA*DT)
      FMA = FLOAT(MA)
      MX = IFIX(ALOG10(FMA)/ALOG10(2.))- 1
    1 MMX = 2**(MX-1)
      IF (MA  .LE. MMX) GO TO 11
      MX = MX + 1
      GO TO 1
   11 NCARDS = (NV-1)/8 + 1
      JL=8*NCARDS-NV
      NV = NV + 1
      M = 0
      LC = 0
      DO 31 I = 1,NCARDS
      LC = LC + 1
      READ 1002, (XR(J), J=1,8)
 2332 FORMAT(8F9.6)
C     READ 1002, (XR(J), J=1,8), K
      IF(I.NE.NCARDS) GO TO 6
      IF(JL.EQ.0) GO TO 6
      JL=9-JL
      DO 9  J=JL,8
    9 XR(J)=0.
    6 PRINT 2330, K, (XR(J), J=1,8)
      K = LC
      IF (K .EQ.LC) GO TO 311
      LC = K
      PRINT 2003, I
C
C   FIND MAX. INPUT ACC. (XMAX)
C
  311 DO 31 J = 1,8,2
      M = M + 1
      X(M) = CMPLX(XR(J),XR(J+1))
   31 CONTINUE
      M = M + 1
      DO 92 I = M,MFOLD
   92 X(I) = 0.
      CALL AMAX(X,MA,XM,NMAX)
      IF (XMAX.LT. .000001) GO TO 900
      XF = XMAX/XM
  903 DO 93 I = 1,M
   93 X(I) = X(I)*XF
      XMAX = XM*XF
      TMAX = FLOAT(NMAX-1)*DT
      PRINT 2014,XM,TMAX,XF,XMAX
C
      CALL RFFT(X,MX,INV,S,IFERR)
C     X(1) = 0.
C
C
C   REMOVE FREQUENCIES ABOVE FMAX AND FIND MAX. ACC. OF NEW MOTION
C
      FREQ = 0.
      SXX = 0.
      SFX = 0.
      DO 99 I = 1,MFOLD
      IF (FREQ.GT.FMAX)    X(I) = 0.
      XA = CABS(X(I))
      SXX= SXX + XA*XA
      SFX = SFX + FREQ*XA*XA
      AR(1,I) = X(I)
      FREQ = FREQ + DF
   99 CONTINUE
      SFX = SFX/SXX
      PRINT 2005,SFX
      IF (FMAX.GT.FREQ) RETURN
      CALL RFSI(X,MX,INV,S,IFERR)
      CALL AMAX(X,MA,XM,NMAX)
      DO 72 I = 1,MFOLD
   72 X(I) = AR(1,I)
      PRINT 2331,XM,FMAX
C
 1001 FORMAT(2I5,  F10.3, [illegible])
 1002 FORMAT(8F9.5,I7)
 1003 FORMAT(8F10.0)
 2331 FORMAT(///21H   MAX ACCELERATION =  F13.5, 22H FOR FREQUENCIES REMOV
     1ED ABOVE F10.2, 7H C/SEC.///)
 2003 FORMAT(17H   ACC. CARD NO. I4,18H OUT OF SEQUENCE  )
 2005 FORMAT(25H MEAN SQUARE FREQUENCY =  F10.2, 7H C/SEC. //)
```

```
2000 FORMAT(2X, I9, 5X, 0P19.6)
2012 FORMAT(1OH EARTHQUAKE  -  .9A8//
    .15,37H ACCELERATION VALUES AT TIME INTERVAL,F10.4//
    259H    THE VALUES ARE LISTED ROW BY ROW AS READ FROM CARDS/
    567H    TRAILING ZEROS ARE ADDED TO GIVE A TOTAL OF, I9,7H VALUES//)
2014 FORMAT(/23H MAXIMUM ACCELERATION =  F9.3/
    1        23H AT TIME             =  F6.2, 4H SEC//
    1 44H THE VALUES WILL BE MULTIPLIED BY A FACTOR = F7.3/
    3 44H TO GIVE NEW MAXIMUM ACCELERATION           = F9.3 //)
     RETURN
     END
```

```
      SUBROUTINE RMAX(R,NR,RMAX,NRMAX)
C
C . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C
C   THIS ROUTINE FINDS MAX. VALUE, RMAX, AND NUMBER OF MAX. VALUE,NRMAX,
C   OF ARRAY R WITH NR NUMBER OF VALUES
C
C   CODED FOR [illegible] SCHNABEL OCT. 1971
C
C . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C
      DIMENSION R(1)
      RMAX = 0.
      DO 1 I = 1,NR
      RA = ABS(R(I))
      IF (RMAX.GT.RA) GO TO 1
      NRMAX = I
      RMAX = RA
    1 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SOIL(NHL)
C
C*****************************************************************
C
C   THIS ROUTINE READS PROPERTIES OF A SOIL PROFILE, ASSIGNS VALUES TO
C   EACH LAYER, CALCULATES EFFECTIVE PRESSURE AND DEPTH IN MIDDLE OF
C   EACH LAYER AND PRINTS THE RESULTS
C
C       IDNT     = IDENTIFIER FOR SOIL PROFILE
C       DL       = RATIO OF CRITICAL DAMPING
C       GL       = SHEAR MODULUS
C       FACT     = FACTOR FOR CALCULATING SHEAR MODULUS FROM STRAIN
C       H        = LAYER THICKNESS
C       R        = DENSITY
C       WL       = UNIT WEIGHT
C       TP       = SOIL TYPE
C       DEPTH    = DEPTH TO MIDDLE OF LAYER
C       WEIGHT   = EFFECTIVE PRESSURE
C       NL       = NUMBER OF LAYERS INCLUDING HALFSPACE
C       NT       = NUMBER OF SUBLAYERS EXCLUDING HALFSPACE
C       NWL      = NUMBER OF FIRST SUBMERGED LAYER
C       NLY      = NUMBER OF SUBLAYERS IN EACH LAYER
C       W        = UNIT WEIGHT
C       VS       = SHEAR WAVE VELOCITY
C       DFAC     = FACTOR ON DAMPING
C       FACTOR   = FACTOR ON SHEAR MODULUS
C       HL       = THICKNESS OF LAYER
C       H        = THICKNESS OF SUBLAYER
C       GMOD     = SHEAR MODULUS
C       D        = CRITICAL DAMPING RATIO
C
C   CODED BY PER B SCHNABEL OCT. 1970
C   MODIFIED APRIL 1972
C
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER TP, TYPE
      COMMON /SOILA/ IDNT(18),GL(20),GL(20),FACT(20),H(20),R(20),DF(20)
      COMMON /SOILA/ FAC(23), GL(23), TP(23), DEPTH(23), WEIGHT(20)
      COMMON /SOILC/ NSOIL,NL
      COMMON /JOB/  NA, GT, SOD
      DIMENSION SCRAM(20)
C
      READ 100,    NSOIL, NL, NWL, IDNT
      PRINT 2030, NSOIL, IDNT
C
C   READ SOIL PROPERTIES FOR EACH LAYER AND ASSIGN VALUES TO EACH SUBLAYER
C
      J = 0
      DO 14 N = 1, NL
      READ 1004, K, TYPE, NLY,   HL, GMOD, D , W, VS, FACTOR , DFAC
      IF (NLY.EQ. 0) NLY = 1
      IF (K .EQ. N) GO TO 141
      PRINT 1336, N
      STOP
C
C   COMPUTE MODULUS FROM SHEARWAVEVELOCITY
  141 IF (GMOD .EQ. 0.) GMOD = VS*VS*W/GT
      DO 14 I = 1,NLY
      J = J+1
      DL(J) = D
      GL(J) = GMOD
      FAC(J)=FACTOR
      FACT(J) =  FACTR
      DF(J) = DFAC
      WL(J) = W
      H(J) = HL/NLY
      TP(J) = TYPE
   14 R(J) = W/GT
      NT = J -1
C   CALCULATE AVERAGE DEPTH AND EFFECTIVE PRESSURE IN EACH LAYER
C
      W1 = WL(1)
      IF (NWL .EQ. 1) W1 = WL(1) - WW
      DEPTH(1) = H(1)/2.
      WEIGHT(1) = H(1)*W1/2.
      SCRAM(1) = WEIGHT(1)*(1.+2.*SOD)/3.
      IF  (NT .EQ. 1)  GO TO 191
      DO 19 I = 2,NT
      W2 = WL(I)
      IF (NWL .LE. I) W2 = WL(I) - WW
      DEPTH(I) = DEPTH(I-1) + H(I)/2. + H(I-1)/2.
      WEIGHT(I) = WEIGHT(I-1) + H(I)*W2/2. + H(I-1)*W1/2.
      SCRAM(I) = WEIGHT(I)*(1.+2.*SOD)/3.
   19 W1 = W2
  191 TD = DEPTH(NT) + H(NT)/2.
      IF (NWL .LT. NT+1)  W3 = DEPTH(NWL)- H(NWL)/2.
      IF (NWL .EQ. NT+1)  WD = DEPTH(NWL-1) + H(NWL-1)/2.
C
C   CALCULATE FACTOR FOR SHEAR MODULUS
      DO 10 I = 1,NT
      IF (TP(I) .EQ. 0) GO TO 10
      IF (DF(I).LT..01) DF(I) = 2.53 - .45*ALOG10(WEIGHT(I)*1000.)
      NTP = TP(I)
      GO TO (101,102,103,104), NTP
  101 IF (FACT(I).LT. .001)  FACT(I) = GL(I)/2500.
      FAC(I) = FACT(I)
      FACT(I) = FACT(I)*1000.
      GO TO 10
  102 IF (FACT(I).LT. .001)  FACT(I) = GL(I)/(1000.*SQRT(SCRAM(I)*1000.))
      FAC(I) = FACT(I)
      FACT(I) = FACT(I)*SQRT(SCRAM(I)*1333.)*1333.
      GO TO 10
  103 IF (FACT(I).LT. .0001)  FACT(I) = SQRT(GL(I)/R(I))/1333.
      FAC(I) = FACT(I)
      FACT(I) = FACT(I)*FACT(I)*1000000.*R(I)
      FACT(I) = FACT(I)/2.
      GO TO 10
  104 FACT(I) = FACT(I)*(WEIGHT(I)*1000.)**(1./3.)*13333.
   10 CONTINUE
  131 PRINT 2071,NL,TD,NWL,WD
      PRINT 2350
      DO 17 I = 1,NT
      VS = SQRT( GL(I)/R(I))
      PRINT 2007, I, TP(I),FAC(I),DF(I), H(I),DEPTH(I)
     1,WEIGHT(I),GL(I),DL(I),WL(I),VS
   17 CONTINUE
      I = NT + 1
      VS = SQRT(GL(I)/R(I))
      PRINT 2107, I, GL(I), DL(I), WL(I), VS
      CALL CRSTIL(NHL)
 1339 FORMAT(I5), 6X0)
 1004 FORMAT(3I5, 4F10.0,F5.0)
```

```
2004 FORMAT(17H   SOIL CARD NO. I4,17H OUT OF SEQUENCE )
2020 FORMAT(29H     NEW SOIL PROFILE NO. I3,9X,17H IDENTIFICATION  6A6
    1/)
2021 FORMAT(17H NUMBER OF LAYERS .I20,10X,16HDEPTH TO BEDROCK.F14.2/
    1 32H NUMBER OF FIRST SUBMERGED LAYER .I5,
    2 10X,20HDEPTH TO WATER LEVEL.F10.2//)
2019 FORMAT(91H LAYER  TYPE     FACTOR     THICKNESS     DEPTH     *
    1 97H   EFF. PRESS.     MODULUS          DAMPING    UNIT WEIGTH
    2 9X, 9HSHEAR VEL /I92.11HMOD.  DAMP. //)
2009 FORMAT(I4,I7,2X,2F6.2,F10.2,F12.2,F13.2,F19.0,F19.3,F19.4,F19.0)
2109 FORMAT(   I4, 4X, 6HBASE  40X, F19.0, F15.3, F19.4, F15.3)
     RETURN
     END
```

```
      SUBROUTINE CHSOIL(NS)
C
C**************************************************************************
C
C   THIS ROUTINE CALCULATES THE COMPLEX SOIL PROPERTIES AND TRANSFER
C   FUNCTIONS FOR THE LAYERS
C
C       NL       = NUMBER OF SOIL LAYERS
C       BL       = RATIO OF CRITICAL DAMPING
C       GL       = SHEAR MODULUS
C       R        = DENSITY
C       G        = COMPLEX SHEAR MODULUS
C       V        = COMPLEX SHEAR WAVE VELOCITY
C       PLUS     = COMPLEX TRANSFER FUNCTION
C       MINUS    = COMPLEX TRANSFER FUNCTION
C
C   CODED BY PER B SCHNABEL OCT 1971
C
C**************************************************************************
C
      COMPLEX G, V, PLUS, MINUS, AU
      COMMON /SOILS/ IDNT(6),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      COMMON /CSOIL/ G(23), V(23), PLUS(23), MINUS(23)
C
      N = NL + 1
      DO 1 I = 1,N
      GIMAG = 2.*BL(I)*GL(I)
      G(I) = CMPLX(GL(I),GIMAG)
      V(I) = CSQRT(G(I)/R(I))
    1 CONTINUE
      DO 2 I = 1,NL
      J = I + 1
      AU = CSQRT(R(I)*G(I)/R(J)/G(J))
      PLUS(I) = (1. + AU)/2.
      MINUS(I)= (1. - AU)/2.
    2 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MOTION(NL,IN,INT,LL,LT, X,AX)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THIS ROUTINE CALCULATES THE MOTION IN ANY TWO SOIL LAYERS OR IN
C   ROCK FROM MOTION GIVEN IN ANY LAYER OR IN ROCK
C
C       NL      = NUMBER OF SOIL LAYERS EXCLUDING ROCK
C       IN      = NUMBER OF LAYER WHERE OBJECT MOTION IS GIVEN
C       INT     = MOTION TYPE
C                 IF EQ 0     OUTCROPPING LAYER
C       LL(I)   = NUMBER OF LAYERS WHERE OUTPUT MOTION IS WANTED
C                 MAX  3 LAYERS
C       LT(I)   = MOTION TYPE
C                 0 - OUTCROPPING LAYER
C                 1 - LAYER WITIN PROFILE
C       X(I)    = OBJECT MOTION
C       AX(I)   = OUTPUT MOTION
C
C
C   CODED BY PER B SCHNABEL  OCT 1970
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER LL(3), LT(3)
      INTEGER TITLE
      COMPLEX AA(3)
      COMPLEX X, AX
      COMPLEX  G, V, PLUS, MINUS
      COMPLEX E, F, EE, FF, A, EX, AIN, IPI2
      DIMENSION X(3333),AX(3,2700),          S(700),INV(70)
      COMMON /EQ/ MFOLD,MA?,TITLE(13),DT, NB , MMA, DF,MX
      COMMON /SOILA/ IDN(10),HL(23),GL(23),FACT(23),H(23),R(20),BF(20)
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
C
C
      IPI2 = CMPLX(0., 6.28)
      DO 20 L = 1,3
      IF (LL(L) .GT. 0) AX(L,1) = X(1)
   20 CONTINUE
      FREQ = 0.
      DO 10 I = 2, MFOLD
      E = 1.
      FF = 1.
      FREQ = FREQ + DF
      A = FREQ*IPI2
      DO 191 K = 1,NL
      IF (K.NE.IN) GO TO 192
      AIN = E + FF
      IF (INT.EQ.0) AIN = 2.*E
C   FIND SUBLAYER WHERE MOTION IS WANTED
  192 DO 11 L = 1,3
      IF (K.NE.LL(L)) GO TO 11
C   AMPLIFICATION FACTOR FOR SUBLAYER WITHIN PROFILE
      AA(L) = E + FF
C   AMPLIFICATION FACTOR FOR OUTCROPPING SUBLAYER
      IF (LT(L).EQ.0)  AA(L) = 2.*E
   11 CONTINUE
      EX = CEXP(H(K)*A/V(K))
      EE = E*EX
      F = FF/EX
      E = EE*PLUS(K) + MINUS(K)*F
      FF = PLUS(K)*F + MINUS(K)*EE
  191 CONTINUE
      IF (IN.NE.NL+1) GO TO 193
      AIN = E + FF
      IF (INT.EQ.0) AIN = 2.*E
  193 DO 21 L = 1,3
      IF (LL(L).NE.NL+1) GO TO 21
      AA(L) = E + FF
      IF (LT(L).EQ.0) AA(L) = 2.*E
   21 CONTINUE
      DO 23 L = 1,3
      IF (LL(L) .GT. 0) AX(L,I) = X(I)*AA(L)/AIN
   23 CONTINUE
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE STRT( IT,NI,DGMAX,PRMUL,X,AX,SA,SP,INV)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THIS ROUTINE CALCULATES STRAIN IN THE MIDDLE OF EACH LAYER AND FIND
C   NEW SOIL PROPERTIES COMPATIBLE WITH THE STRAINS
C
C       IT       = ITERATION NUMBER
C       NI       = NUMBER OF LAYERS EXCLUDING ROCK
C       DGMAX    = MAX ERROR IN SOIL PARAMETERS B OR G IN PERCENT
C       X        = OBJECT MOTION
C       AX(1, I) = ACCELERATION VALUES AT THE SURFACE
C       AX(2, I) = INCIDENT WAVE-COMPONENT
C       AX(3, I) = REFLECTED WAVE-COMPONENT
C       PRMUL    = RATIO EFF. STRAIN/MAX. STRAIN
C
C   CODED PER B SCHNABEL OCT. 1970
C   MODIFIED PBS  SEPT. 1971
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER TITLE,TP
      COMPLEX IPI2, EX, E, F, EE, FF
      COMPLEX X, AX
      COMPLEX G, V, PLUS, MINUS
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON /SOILA/ IDNT(5),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      COMMON /SOILB/ FAC(20), WL(20), TP(20), DEPTH(20), WEIGHT(20)
      COMMON /SOILC/ MSOIL,MWL
      COMMON /SOILDW/ S(9,20), AS(9,20), BS(9,20), NV(9)
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
      DIMENSION TMAX(20),           EMAX(20),STR(20)
      DIMENSION XI(60), AX(3, 64), SA(2,120),SP(50), INV(10)
C
      DO 43 I = 1,MFOLD
      AX(1,I) = REAL(X(I))
   43 AX(2,I) = AIMAG(X(I))
      DO 1  I = 1,MFOLD
      AX(2,I) = AX(1,I)/2.
    1 AX(3,I) = AX(2,I)
      PI2=6.283
      IPI2=CMPLX(0.,PI2)
      GT = 32.2
      DO 2 K = 1,NI
      FREC = 0.
      X(1) = 0.
      FF = GT/(IPI2*V(K))
      EE = H(K)/2.*(IPI2/V(K))
      DO 20 I = 2,MFOLD
      FREQ = FREQ + DF
      EX = CEXP(FREQ*EE)
      X(I) = (AX(2,I)*EX - AX(3,I)/EX)*FF/FREQ
      EX = EX*EX
      E = AX(2,I)*EX
      F = AX(3,I)/EX
      AX(2,I)= PLUS(K)*E + MINUS(K)*F
      AX(3,I)= PLUS(K)*F + MINUS(K)*E
   20 CONTINUE
      EMAX(K) = 0.
C
C   DETERMINE MAX. STRAIN BY INVERTING FOURIER TRANSFORM OF STRAIN
C   INTO THE TIME DOMAIN
C
      CALL RFSN(X,MX,INV,SP,IFERR)
      CALL XMAX(X,MA,XMAX,KXMAX)
C
      EMAX(K) = XMAX
      TMAX(K) = FLOAT(KXMAX-1)*DT
    2 CONTINUE
      IF (IT.GT.1) PRINT 2007
      PRINT 2017, TITLE, IDNT
      PRINT 2327,IT
      PRINT 2037, PRMUL
      PRINT 2333
      DGMAX = 0.
      DO 23 I = 1,NI
      EM = EMAX(I)*PRMUL*100.
      EMAX(I) = EMAX(I)*100.
      IF (TP(I) .NE. 3)  GO TO 231
      STR(I) = EMAX(I)*GL(I)*10.
      PRINT 2107, I, TP(I), DEPTH(I), EM , BL(I), GL(I)
      GO TO 23
C
C   USE EFFECTIVE STRAIN AMPLITUDE (EM) TO GET NEW VALUES FOR DAMPING
C   AND SHEAR MODULUS
  231 IN = TP(I)*2 - 1
      SS= ABS(EM)
      SL = ALOG10(SS)
      LL = NV(IN)
      DO 31 L = 1,LL
      IF (SS.LE. S(IN,L)) GO TO 311
   31 CONTINUE
      L = LL
  311 GN =AS(IN,L)*SL +BS(IN,L)
      GG = GN*FACT(I)/1000.
      IN = IN + 1
      LL = NV(IN)
      DO 32 L = 1,LL
      IF (SS.LE. S(IN,L)) GO TO 321
   32 CONTINUE
      L = LL
  321 B  =AS(IN,L)*SL +BS(IN,L)
      B = B*BF(I)
C
      STR(I) = EMAX(I)*GG*10.
      B = B/100.
      DG = (GG - GL(I))*100./GG
      DB = (B - BL(I))*100./B
      PRINT 2007, I, TP(I), DEPTH(I), EM, B, BL(I), DB, GG, GL(I), DG
      IF (ABS(DG) .GT. DGMAX)  DGMAX = ABS(DG)
      IF (ABS(DB) .GT. DGMAX)  DGMAX = ABS(DB)
      BL(I) = B
      GL(I) = GG
   23 CONTINUE
      PRINT 2361
      PRINT 2001, (I,TP(I), H(I),DEPTH(I), EMAX(I), STR(I), TMAX(I),
     1 I = 1,NI)
      CALL CRSOIL(NI)
      DO 44 I = 1,MFOLD
   44 X(I) = CMPLX(AX(2,I),AX(3,I))
      RETURN
```

```
C
 2000 FORMAT(2X,5HLAYER,[illegible],6X,[illegible]EFF. STRAIN%,
     1[illegible] USED,[illegible]
     2,[illegible]///)
 1002 FORMAT(1H1)
 2311 FORMAT(////[illegible] VALUES IN TIME DOMAIN //
     1 3X, 5HLAYER 2X,[illegible]TYPE 6X, [illegible]THICKNESS 10X, 5HDEPTH 5X, 10HMAX STR
     2AIN 5X, 10HMAX STRESS 10X, [illegible] /
     3[illegible]
 2001 FORMAT(2I5, 2F15.1, F15.[illegible],2F15.2)
 2337 FORMAT(2I5  , F12.1,        5X, F12.5, 5X, 2F12.5, F12.1, 5X,
     1 2F12.5, F12.1)
 2107 FORMAT(2I5, F12.1, 5X, F12.5,[illegible],F12.5,[illegible],F12.5)
 2327 FORMAT([illegible]  ITERATION NUMBER   I3)
 2017 FORMAT(5X,19H[illegible]    - [illegible],19HSOIL PROFILE -   [illegible]
 2337 FORMAT([illegible]  THE CALCULATION HAS BEEN CARRIED OUT IN THE TIME DOMAI
     1N WITH EFF. STRAIN = F5.2, [illegible] MAX. STRAIN /)
      END
```

```
      SUBROUTINE UTPRI(A,DPTH,LS,R2,LN,LT,S,AR,AA,S,INV)
C
C
C****************************************************************************
C
C     THIS ROUTINE TRANSFERS THE VALUES IN ARI(N, I INTO THE TIME DOMAIN
C     IN RI I, PRINTS AND PUNCHES OUT THE RESULTS.
C
C
C        [illegible]      = [illegible] MAX. ACC.
C                   [illegible] PRINT MAX ACC. SEPARATELY
C        DPTH     = DEPTH OF LAYER
C        RI I     = OBJECT MOTION
C        ARI(S, I = COMPUTED MOTION
C        LS       = COMPUTED MOTION NUMBER
C                   [illegible] IF OBJECT MOTION
C        LN       = SUBLAYER NUMBER
C        LT       = SUBLAYER TYPE
C                   0 - OUTCROPPING
C                   1 - [illegible]
C        AA,S,INV  SCRATCH ARRAYS
C
C     CODED  [illegible] SCHNABEL  OCT. 1970
C     MODIFIED [illegible] DEC. 1971
C
C****************************************************************************
C
      INTEGER TITLE
      COMPLEX [illegible]
      COMPLEX S, AR
      DIMENSION [illegible]
      DIMENSION [illegible]
      COMMON /[illegible]/ [illegible]
      COMMON /[illegible]/ [illegible],TITLE(19),DT, [illegible]
C
      [illegible] = 0.
      SPR = 0.
      [illegible] = 0.
C     TRANSFORM VALUES IN [illegible] INTO THE TIME DOMAIN
      DO 20  I = 1,[illegible]
      IF (LS.EQ.0) GO TO 201
      SAVE = R(I)
      R(I) = ARI(S,I)
      ARI(S,I) = SAVE
  201 [illegible] = CABS(R(I))
      [illegible]
      SPR = SPR + [illegible]
      [illegible]
   20 CONTINUE
      SPR = SPR/[illegible]
C
      CALL [illegible](R,[illegible],1.[illegible])
C
      CALL [illegible]
      [illegible] = DT*FLOAT([illegible]-1)
      [illegible] = 0.
      [illegible] = [illegible]/2)
      [illegible]
      [illegible]
      DO 29 I = [illegible]
      [illegible] = [illegible]
```

```
      RADS = ABS(RADS)
      IF (RADS.GT.REND) REND = RADS
      RADS = AIMAG(X(I))
      RADS = ABS(RADS)
      IF (RADS.GT.REND) REND = RADS
   19 CONTINUE
      REND = REND/RMAX
C
C   PRINT AND OR PUNCH OUTPUT
      N = 1
      NN = 4
      NCARDS=NR/8
      NC = NCARDS
      IF (N2.EQ.0) NC = 0
      IF (NR.EQ.9) GO TO 292
      IF (LT.EQ.3)  PRINT 2339,LN, IDNT
      IF (LT.EQ.1)  PRINT 2002,LN, IDNT
      PRINT  2005, SFR
      PRINT 2003, RMAX, TMAX
  292 IF (NR.EQ.9.AND.LT.EQ.0)  PRINT 2001, DPTH,RMAX,TMAX,SFR,REND,NC
      IF (NR.EQ.9.AND.LT.EQ.2)  PRINT 2313, DPTH,RMAX,TMAX,SFR, REND,NC
      IF (N2.EQ.0) GO TO 202
      PUNCH 2000, RMAX, TITLE
      IF (LT.EQ.1)  PUNCH 2002,LN, IDNT
      IF (LT.EQ.0)  PUNCH 2000,LN, IDNT
      DO 20 I = 1,NCARDS
      K = 0
      DO 201 J = N,NN
      K = K+ 1
      RO(K) = REAL(X(J))
      K = K + 1
      RO(K) = AIMAG(X(J))
  201 CONTINUE
      PUNCH 2390,(RO(J),J=1,8),I
      IF (N2 .EQ. 2) PRINT 2019, (RO(J), J = 1,8), I
      NN = 4 + NN
      N = N + 4
   20 CONTINUE
  202 CALL RFFT(X,NR,INV,S,IFERR)
      IF (LS.EQ.0)   RETURN
      DO 27 I = 1,NPOLD
      SAVE = AX(LS,I)
      AX(LS,I) = X(I)
   27 X(I) = SAVE
      RETURN
C
 2000 FORMAT(45H  ACCELERATION VALUES AT OUTCROPPING LAYER 19.3H - 6001
 2001 FORMAT(9X,6HDEPTH, F13.1,F19.5,2F19.2,F20.3,I20/)
 2313 FORMAT(9X,6HDEPTH, F13.1,F19.5,2F19.2,F23.3,I23/)
 2002 FORMAT(62H  ACCELERATION VALUES AT THE TOP OF LAYER I3.3H - 6A0)
 2003 FORMAT(/19H  MAX. ACC. =  F9.6,11H AT TIME = F6.3, 5H SEC. //)
 2005 FORMAT(/26H   MEAN SQUARE FREQUENCY = F10.2/)
 2006 FORMAT(21X,6HTIME  F7.4,5A8)
 2390 FORMAT(2X, I5, 5X, 8F15.6)
 2009 FORMAT(8F9.6,I7)
 2010 FORMAT(8F10.6,I10)
      END

      SUBROUTINE RESP(LL,LN,LS,NR,N,NE,R,S,INV)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C   THIS PROGRAM READS DATA FOR RESPONSE SPECTRUM ANALYSIS
C   NECESSARY SUBROUTINES    DRCTSP,  CNPMAX, PLOT
C
C            = RESPONSE SPECTRUM NUMBER
C      NR    = NUMBER OF DAMPING VALUES
C      ND    = SWITCH
C      NAV        EQ 0  ACCELERATION SPECTRUM
C                 EQ 1  VELOCITY SPECTRUM
C                 EQ 2  ACC. AND VEL. SPECTRUM
C            = SWITCH
C      NPL        EQ 1  PLOT RESPONSE SPECTRA ACCORDING TO NAV
C            = SWITCH
C      NP         EQ 0  NO PUNCHED OUTPUT
C                 NE 0  PUNCHED OUTPUT ACCORDING TO NAV
C            = FOURIER TRANSFORM OF OBJECT MOTION
C      R     = FOURIER TRANSFORM OF COMPUTED MOTIONS
C      DR    = PERIOD STEPS
C      DN    = NUMBER OF EACH STEP
C      NN    = PERIODS WHERE RESPONSE IS TO BE COMPUTED
C      T
C
C   CODED PER B SCHNABEL DEC. 1970
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C * * * * * * * * * * * * * * * * * * * * * * * * [illegible],DF(23)
C
      COMMON /SOILP/ [illegible](9),GL(23),CL(23),FACT(23),H(23),R(23),
      INTEGER [illegible] 12
      COMMON /EQ/ NP,IL,NMAX,TITLE(5),DT, NA , NNA, DF,NR
      COMMON /EVAL/ NN(9), IL0(6),T(100), SA(5,100),SV(5,100)
      COMPLEX R, AR
      DIMENSION R(NP), AX(3,NA), A(2,64), SE(9),INV(10)
      DIMENSION D(9,11), ABS(5,10)
      DIMENSION DW(5), NW(4)
      DATA IBLANK /6H      /
      DATA (ABS(I), I = 1,10)/6H PERIO, 6HD IN S, 6HEC.   ,[illegible]
C
      READ 1000, ND, NP, NAV, NPL, NPRO
      READ 9000, (EL(I), I = 1,ND)
      PRINT 9330, LN, (EL(I), I = 1,ND)
      IF (NPRO.LE.2) GO TO 9
      T1 = .040
      TQ = 9
      N = 10
      K = 2
      IF (NPRO.EQ.3)  GO TO 91
      T1 = .040
      N = 25
   91 CALL STEP(K,N,DN,DR,T1,TN,T,NNN)
      GO TO 131
    9 NN(1) = 1
      NN(2) = 9
      NN(3) = 9
      NN(4) = 4
      DW(1) = .040
      DW(2) = .1
      DW(3) = .2
      DW(4) = .4
      IF (NPRO.EQ.0) GO TO 6
      GO TO (1, 2), NPRO
```

```
    1 DO 21 I = 2,4
      NN(I) = NN(I)*2
      DW(I) = DW(I)*.5
   21 CONTINUE
      GO TO 4
    2 NN(2) = 99
      NN(3) = 73
      NN(4) = 30
      DW(1) = .048
      DW(2) = .379
      DW(3) = .0[illegible]
      DW(4) = .1
    4 N = 0
C
C   GENERATE PERIODS IN T
      T(1) = .03[illegible]
      DO 10 L = 1,4
      M = NN(L)
      DO 10 I = 1,M
      N = N+1
      T(N+1) = T(N) + DW(L)
   10 CONTINUE
      NPER = N + 1
C
  131 [illegible]
C   SAVE VALUES [illegible]
      DO 1[illegible] I = [illegible]
      [illegible]
      [illegible]
      IF [illegible] GO TO 11
      [illegible]
   11 CONTINUE
C
C   TRANSFORM VALUES [illegible] BACK INTO THE TIME DOMAIN
      CALL [illegible]
      DO 1[illegible] L = 1,[illegible]
      IF [illegible]
      [illegible]
      DO 1[illegible] I = 1,9
  1[illegible] [illegible]
      DO 112 I = [illegible]
      [illegible]
      IF [illegible]
  1[illegible] CONTINUE
C
C   COMPUTE RESPONSE FOR ACCELERATION VALUES IN GAL., FOR THE PERIODS
C   GIVEN IN T [illegible]
      CALL            [illegible]
   13 CONTINUE
C
C   [illegible] VALUES
      DO 12 I = [illegible]
   12 [illegible] = CMPLX([illegible])
      IF [illegible]
      IF [illegible] GO TO 133
      PRINT [illegible]
      SC = 0.
      CALL PLCT[illegible],1001)
      IF [illegible] GO TO 1[illegible]
  13[illegible] PRINT 2002
      SC = [illegible]
      CALL PLCT[illegible],1001)
  1[illegible] NN = 0
      RETURN
 1333 FORMAT([illegible])
 2001 FORMAT([illegible]    PLOT OF ACCELERATION SPECTRA ///)
 2002 FORMAT([illegible]    PLOT OF VELOCITY SPECTRA ///)
 [illegible] FORMAT( [illegible]F10.3)
 [illegible] FORMAT( 50H  RESPONSE SPECTRUM ANALYSIS FOR LAYER NUMBER      I4
     1/20H CALCULATED FOR DAMPING     F13.3)
      END
```

```
      SUBROUTINE SPECTRA(NN, NG, DT, NP, N4, N2, ID, D, T, A)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C   THIS ROUTINE COMPUTES RESPONSE SPECTRA BY THE STEP BY STEP METHOD
C
C        NN      = RESPONSE SPECTRUM CURVE NUMBER  USED IN PLOTTING
C        NG      = NUMBER OF ACCELERATION VALUES
C        DT      = TIMESTEP BETWEEN EACH ACCELERATION VALUE
C        NP      = NUMBER OF PERIODS FOR WHICH RESPONSE IS TO BE COMPUTED
C        T       = ARRAY WITH THE PERIODS
C        A       = ACCELERATION VALUES
C        D       = CRITICAL DAMPING RATIO
C        ID      = IDENTIFICATION
C        N4      = 0 - ACCELERATION SPECTRUM
C                  1 - VELOCITY SPECTRUM
C                  2 - ACC. AND VEL. SPECTRA
C        N2      = 0 - NO PUNCHED OUTPUT
C                  1 - PUNCHED OUTPUT ACCORDING TO N4
C
C
C   CODED BY I. M. IDRISS 1968
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      DIMENSION A(1)
      COMMON /RVAL/ NAC(90), ZLO(6),T(100), SA(5,100),SV(5,100)
      DIMENSION       PRV(100), PAA(100), RD(100)
      DIMENSION ID(9,11)
C
      GT = 32.2
      DO 10 K = 1, NG
      A(K) = GT*A(K)
   10 CONTINUE
      NGG = NG-1
      PRINT 112,D
      N = 1
      VV = SQRT(1.-D*D)
      DO 200 LOOP = 1, NP
      W = 6.2831853/T(M)
      WC = VV*W
      W2 = W*W
      W3 = W2*W
      CALL COMPARE(NGG,   T(M),D,W2,W3,WD,D,DT,ZD,ZV,ZA,A)
      SV(NN,M) = ZV
      SA(NN,M) = ZA/GT
      RD(M) = ZD
      PRV(M) = W*ZD
      PAA(M) = W2*ZD/GT
  200 M = M + 1
      PRINT 912, (ID(NN,I), I = 1,10),D
      SUMSV = 0.
      SUMSA = 0.
      SUMT  = 0.
      SUMAV = 0.
      SUMAA = 0.
      TT1 = .1
      TT2 = 0.
      DO 920 M = 1, NP
      FREQ = 1./T(M)
      IF (T(M) .LT. .0999 .OR. TT2.GT.2.49999)  GO TO 920
      TT2 = (T(M+1) + T(M))/2.
      IF (TT2.GT.2.5)  TT2 = 2.5
      TT = TT2 - TT1
      SUMSA = SA(NN,M)*TT + SUMSA
      SUMSV = SV(NN,M)*TT + SUMSV
      SUMT = SUMT + TT
      TT1 = TT2
      IF (SUMAV.LT.SV(NN,M))  SUMAV = SV(NN,M)
      IF (SUMAA.LT.SA(NN,M))  SUMAA = SA(NN,M)
  920 PRINT 922,M,T(M),RD(M),SV(NN,M),PRV(M),SA(NN,M),PAA(M),FREQ
      PRINT 2001,SUMSA,SUMSV,SUMAA,SUMAV
 2001 FORMAT(///10X,40HVALUES IN PERIOD RANGE .1 TO 2.5 SEC.          //
     119X35HAREA OF ACC. RESPONSE SPECTRUM    =  F10.3/
     219X35HAREA OF VEL. RESPONSE SPECTRUM    =  F10.3/
     319X35HMAX. ACCELERATION RESPONSE VALUE =   F10.3/
     419X35HMAX. VELOCITY     RESPONSE VALUE =   F10.3//)
      IF (N2.EQ.0) GO TO 90
      IF (N4 .EQ. 0) GO TO 91
      PUNCH 412, NN,(SA(NN,I), I = 1,NP)
      PUNCH 402, (SA(NN,I), I = 1,NP)
   91 IF (N4 .EQ. 1) GO TO 90
      PUNCH 413 , NN,(SV(NN,I), I = 1,NP)
      PUNCH 402, (SV(NN,I), I = 1,NP)
   90 NP = P
      DO 11 K = 1,NG
   11 A(K) = A(K)/GT
      RETURN
C
  112 FORMAT(///,9X,43HTIMES AT WHICH MAX. SPECTRAL VALUES OCCUR /
     1 10X,33HTD = TIME FOR MAX. RELATIVE DISP. /
     2 10X,33HTV = TIME FOR MAX. RELATIVE VEL.  /
     3 10X,33HTA = TIME FOR MAX. ABSOLUTE ACC.   /
     4 9X, 19HDAMPING RATIO =  F9.2//)
  912 FORMAT(1H1,9X,17HSPECTRAL VALUES--  /10X,10A8,9X,
     115HDAMPING RATIO =
     8 F9.2//9X,3HNO..6X,6HPERIOD,9X,10HREL. DISP..6X,9HREL. VEL..9X,
     1 ...,9X,12HPSU.ABS.ACC.  5X,5HFREQ. /
     2 12HPSU.REL.VEL..6X,9HABS. ACC..5X,12HPSU.ABS.ACC. 5X,5HFREQ. /
     3 ...SEC. 11X,3HFT. 8X,8HFT./SEC. 7X,8HFT./SEC. 11X,1HG.10X,1HG.
     ...,6HC/SEC.    //)
  922 FORMAT(I10,F10.2,9E15.5,F10.2)
  402 FORMAT(8F9.5)
  412 FORMAT(15,25H ACC. RESPONSE VALUES FOR   , 8A8)
  413 FORMAT(15,25H VEL. RESPONSE VALUES FOR   , 8A8)
C
      END
```

```
      SUBROUTINE CMPMAX (RUG,   PR,W,W2,W3,W0,D,DT,ZD,ZV,ZA, UG)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     THIS ROUTINE COMPUTES RESPONSE VALUES FOR ONE SINGLE DEGREE OF
C     FREEDOM SYSTEM USING STEP BY STEP METHOD
C
C     EXPLANATICS TO PARAMETERS GIVEN IN DRCTSP
C
C     CODED BY I. M. IDRISS  1968
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      DIMENSION      XD(2), XV(2), T(3)
      DIMENSION UG(1)
C
      ZA = 0.
      ZD = 0.
      ZV = 0.
      XD(1) = 0.
      XV(1) = 0.
      F1 = 2.*D/(W3*DT)
      F2 = 1./W2
      F3 = D*W
      F4 = 1./W0
      F5 = F3*F4
      F6 = 2.*F3
      E = EXP(-F3*DT)
      S = SIN(W0*DT)
      C = COS(W0*DT)
      G1 = E*S
      G2 = E*C
      H1 = W0*G2 - F3*G1
      H2 = W0*G1 + F3*G2
      DO 100 K = 1, RUG
      Y = K-1
      DUG = UG(K+1) - UG(K)
      Z1 = F2*DUG
      Z2 = F2*UG(K)
      Z3 = F1*DUG
      Z4 = Z1/DT
      B = XD(1) + Z2 -Z3
      A = F4*XV(1) + F5*B + F4*Z4
      XD(2) = A*G1 + B*G2 + Z3 - Z2 - Z1
      XV(2) = A*H1 - B*H2 - Z4
      XD(1) = XD(2)
      XV(1) = XV(2)
      ZA = -F6*XV(1) - W2*XD(1)
      F = ABS(XD(1))
      G = ABS(XV(1))
      H = ABS(ZA)
      IF(F .LE. ZD) GO TO 75
      T(1) = Y
      ZD = F
   75 IF(G .LE. ZV) GO TO 80
      T(2) = Y
      ZV = G
   80 IF(H .LE. ZA) GO TO 100
      T(3) = Y
      ZA = H
  100 CONTINUE
      DO 110 L = 1, 3
  110 T(L) = DT*T(L)
      PRINT 112, PR, (T(L),L=1,3)
  112 FORMAT(3X,5HPER = F5.2,5X,19HTIMES FOR MAXIMA -- ,3X,
     14HTD = F8.4,3X,4HTV = F8.4,3X,4HTA = F8.4)
      RETURN
      END
```

```
      SUBROUTINE STRAIN( LL, LGS, LPCH, LPL,LNV,SK,X,AX,AA,NI,S,INV)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THIS SUBROUTINE COMPUTES STRAIN AND/OR STRESS TIME-HISTORY AT THE
C   TOP OF ANY LAYER FOR ACCELERATION HISTORY KNOWN IN ANY LAYER
C   TWO RESPONSE HISTORIES ARE COMPUTED IN ONE RUN
C
C        LL    =   SUBLAYER NUMBER WHERE RESPONSE IS TO BE COMPUTED
C        LGS   =   SWITCH FOR STRESS OR STRAIN
C        LPCH  =   SWITCH FOR PUNCHED OUTPUT
C        LPL   =   SWITCH FOR PLOT
C        SK    =   SCALE FOR PLOTTING
C        X     =   FOURIER TRANSFORM OF OBJECT MOTION
C        AX(1, )   FOURIER TRANSFORM OF SURFACE MOTION
C        AX(2, )   FOURIER TRANSFORM OF FIRST COMPUTED RESPONSE
C        AX(3, )   FOURIER TRANSFORM OF SECOND RESPONSE
C        AA(1, )   TIME HISTORY OF FIRST RESPONSE
C        AA(2, )   TIME HISTORY OF SECOND RESPONSE
C
C
C   CODED BY PER B. SCHNABEL  JULY 1971
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER TITLE,IP
      COMPLEX X, AX
      COMPLEX G, V, PLUS, MINUS
      COMPLEX E,F,EE, A,AM,IPI2, AE,AF,EX,AI
      DIMENSION ABSIS(10)
      DIMENSION AE(2), AF(2)
      DIMENSION X(1), AX(3,1), AA(2,1),S(1),INV(1)
      DIMENSION  LL(2),  LGS(2), LPCH(2), LPL(2),SK(2),LNV(2)
      COMMON /SOILA/ IDNT(6),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      COMMON /SOILB/ FAC(20), WL(20), TP(20), DEPTH(20), WEIGHT(20)
      COMMON /CSOIL/ G(29), V(20), PLUS(20), MINUS(20)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MM4, DF,MX
      COMMON /CCG/ IC(9,11),T(2049)
C
      IPI2 = CMPLX(0.,6.283)
      GT = 32.2
      AX(2,1) = 0.
      AX(3,1) = 0.
      FREQ = 0.
      DATA (ABSIS(I), I=1,10)/6H TIME ,6HIN SEC , 8*6H
      AI = GT/IPI2
C
C   STARTING AT THE SURFACE THE STRAIN IS COMPUTED SUCCESSIVELY DOWNWARDS
C   FOR EACH FREQUENCY
      DO 1 I = 2,MFOLD
      E = AX(1,I)/2.
      F = E
      FREQ = FREQ + DF
      AM = AI/FREQ
      A = FREQ*IPI2
      DO 11  N = 1,NI
      DO 12 L = 1,2
      IF (N.NE.LL(L)) GO TO 12
      AE(L) = E/V(N)
      AF(L) = F/V(N)
   12 CONTINUE
      EX = CEXP(H(N)*A/V(N))
      E = E*EX
      F = F/EX
      EE = E*PLUS(N) + MINUS(N)*F
      F  = F*PLUS(N) + MINUS(N)*E
      E = EE
   11 CONTINUE
      DO 13 L = 1,2
      IF (LL(L).NE.NI+1) GO TO 13
      AE(L) = E/V(NI+1)
      AF(L) = F/V(NI+1)
   13 CONTINUE
      DO 14 L = 1,2
      IF (LL(L).LE.0) GO TO 14
      N = LL(L)
      EX = CEXP(H(N)*A/(2.*V(N)))
      AX(L+1,I) = (AE(L)*EX - AF(L)/EX)*AM
   14 CONTINUE
    1 CONTINUE
      DO 2 I = 1,MFOLD
    2 AX(1,I) = X(I)
      DO 3 L = 1,2
      IF (LL(L).EQ.0) GO TO 3
      X(1) = 0.
      DO 31 I = 2,MFOLD
   31 X(I) = AX(L+1,I)
      CALL RFSN(X,MX,INV,S,IFERR)
      DO 32 I =1,MFOLD
      AA(L,2*I-1) =REAL(X(I))*100.
   32 AA(L,2*I) = AIMAG(X(I))*100.
    3 CONTINUE
C
      DO 4 I = 1,MFOLD
    4 X(I) = AX(1,I)
C
C   COMPUTE STRESS IF WANTED AND    PUNCH AND PLOT COMPUTED RESPONSES
      DO 9 L = 1,2
      IF (LL(L) .EQ. 0) GO TO 9
      NVAL = LNV(L)
      IF (NVAL.LE.0) NVAL = MA
      IF (NVAL.GT.MA)  NVAL = MA
      IF (NVAL.GT.2049) NVAL = 2049
      DO 91 I = 1,5
   91 IC(L,I) = TITLE(I)
      N = LL(L)
      IC(L,6) = 6HSTRAIN
      IF (LGS(L) .EQ.0) GO TO 93
      IC(L,6) = 6HSTRESS
      DO 92 I = 1,NVAL
   92 AA(L,I) = G(N)*AA(L,I)/100.
   93 IF (LPCH(L).EQ.0) GO TO 94
      PUNCH 2000, (IC(L,I), I=1,11),N
      N = 1
      NCARDS = NVAL/8
      DO 99 K = 1,NCARDS
      NN = N + 7
      PUNCH 2001,(AA(L,I), I = N,NN), K
   99 N = N + 8
   94 IF (LPL(L).EQ.0) GO TO 9
      N = 0
      NSKIP = 1
```

```
      DO 96 I = 1,NVAL,NSKIP
      N = N + 1
      IF (NSKIP.GT.1) AA(1,N) = AA(L,I)
   96 T(N) = DT*FLOAT(I-1)
      IF  (LGS(L).EQ.0)  PRINT 2002
      IF (LGS(L).EQ.1)  PRINT 2003
      IF (LPL(L).EQ.0) GO TO 5
      IF (LPL(2).EQ.2) GO TO 99
      IF (L.EQ.1)  GO TO  98
      DO 97 I = 1,N
   97 AA(1,I) = AA(2,I)
      DO 90 I = 1,11
   90 ID(1,I) = ID(2,I)
   98 CALL PLOT11(  N,T,AA,ABSIS,ID,SC(L),2, N)
      GO TO 5
   99 CALL PLOT12(  N,T,AA,ABSIS,ID,SC(L),2, N)
    5 CONTINUE
      RETURN
 2000 FORMAT(I10,9HLAYER I5)
 2001 FORMAT(8F9.6,I7)
 2002 FORMAT(41H1  TIME HISTORY OF STRAIN IN PERCENT        //)
 2003 FORMAT(41H1  TIME HISTORY OF STRESS IN KIPS          //)
      END
```

```
      SUBROUTINE CG
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * - * * * * * *
C
C   THE SUBROUTINE READ POINTS ON A CURVE AND GENERATES NEW POINTS
C   BETWEEN THE GIVEN POINTS IN ARITHMETIC OR HALFLOGARITHMIC SCALE
C   NECESSARY SUBROUTINES    CURVEG(),  PLOT()
C
C        NST       = NUMBER OF SOILTYPES
C        ABSIS     = TITLE ON ORDINATE FOR PLOTTING
C        NN        = NUMBER OF VALUES IN EACH 10 FOR SEMILOGPLOT
C        SC        = SCALE FOR PLOTTING
C        NC        = NUMBER OF CURVES
C        NV        = NUMBER OF VALUES WHERE STRAIN/PROPERTY-RELATION
C                    IS GIVEN
C        PPL       = MULTIPLICATION FACTOR FOR PLOTTING
C        ID        = IDENTIFICATION
C        X         = STRAIN VALUES
C        Y         = PROPERTY VALUES
C
C
C   CODED BY PER B SCHNABEL SEPT 1970
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      DIMENSION V(9,200), TSTEP(9)
      DIMENSION NT(9),                            ABSIS(10), PPL(9)
      COMMON /SOILOG/ X(9,23), A (9,23), B (9,23), NV(9)
      COMMON /CCG/ ID(9,11),T(200), Y(9,200)
      DATA (ABSIS(I),I=1,10)/6H STRAI ,6HN IN P ,6HERCENT ,7*6H
C
      READ 1000, NSOILT,NPL,NN,SC
      NC = 2*NSOILT
      DO 1 L = 1,NC
      READ 2001, NV(L), PPL(L), (ID(L,I), I=1,11)
      N = NV(L)
      READ 1002,( X(L,I), I = 1,N)
      READ 1002,( Y(L,I), I = 1,N)
    1 CONTINUE
      CALL CURVEG( NC, NV,  2, 4, 0, 10, TSTEP, NT, T, V, X, 0, NSTEP)
      IF (NPL.NE.1) RETURN
      DO 2 N = 1,NC
      DO 2 L = 1,NSTEP
      V(N,L) = V(N,L)*PPL(N)
    2 CONTINUE
      PRINT 3030
      PRINT 3000
      DO 3 L = 1,NC
    3 PRINT 3002, (ID(L,I), I = 1,10), PPL(L)
      CALL     PLOT(NC, NSTEP, T, V, ABSIS, ID, SC, 0, 200)
      RETURN
C
 1000 FORMAT(3I5,F10.3)
 1001 FORMAT(/I5,F10.2, 11A6)
 1002 FORMAT(8F10.3)
 2001 FORMAT(I5, F5.2, 11A6)
 2002 FORMAT( 12F10.4)
 3000 FORMAT(53H  MODULUS AND DAMPING VALUES ARE SCALED FOR PLOTTING //)
 3001 FORMAT(59H     CURVES FOR RELATION STRAIN VERSUS SHEAR MODULUS AND
     1 ON DAMPING ///)
 3002 FORMAT(1X10A6, 26H  MULTIPLICATION FACTOR = F7.3)
```

```
      SUBROUTINE  CURVEGI(NC, NV, KI, A, B, NN, TSTEP, NT, T,V,X,Y,NSTEP)
C
C*****************************************************************************
C
C   THE PROGRAM GENERATES NEW POINTS ON A CURVE BY LINEAR INTERP. IN
C   AN ARITHMETIC OR HALFLOGARITHMIC SCALE
C
C        NV(I)    = NUMBER OF VALUES ON CURVE I
C        NC       = NUMBER OF CURVES
C        KI       =    SWITCH     KI = 1  ARITHMETIC SCALE
C                                 KI = 2  HALFLOGARITHMIC SCALE
C        A,B      =    PARAMETERS FOR CALCULATING NEW VALUES
C                      Y = A*X + B
C        X,Y      =    KNOWN POINTS ON CURVE
C        T        =    VALUES ON ABSISSA WHERE NEW POINTS ARE GENERATED
C        V        =    NEW ORDINATE VALUES
C
C        ARITHMETIC SCALE  KI = 1
C        NN       =    NUMBER OF INTERVALS
C        TSTEP    =    LARGEST VALUE IN EACH INTERVAL
C        NT       =    NUMBER OF STEPS IN EACH INTERVAL
C
C        HALFLOGARITHMIC SCALE
C        NN       =    NUMBER OF VALUES IN EACH LOG10
C
C
C   CODED BY PER B SCHAAREL SEPT 1973
C
C*****************************************************************************
C
      DIMENSION X(9,20), Y(9,20), A(9,20), B(9,20), NV(9), TSTEP(9)
      DIMENSION NT(9), T(233), V(9,233)
      XMIN = 1000000000.
      XMAX = 0.
      DO 1 L = 1,NC
      N = NV(L)
      IF (XMAX .LT. X(L,N))   XMAX = X(L,N)
      IF (XMIN .GT. X(L,1)) XMIN = X(L,1)
      N = N - 1
      DO 1 I = 1,N
      X1 = X(L,I)
      X2 = X(L,I+1)
      IF (KI .EQ. 2)  X1 = ALOG10(X1)
      IF (KI .EQ. 2)  X2 = ALOG10(X2)
      X(L,I) = X(L,I+1)
      A(L,I) = (Y(L,I+1) - Y(L,I))/(X2 - X1)
    1 B(L,I) = -A(L,I)*X1 + Y(L,I)
C
      CALL STEPG(KI, NN, TSTEP, NT, XMIN, XMAX, T, NSTEP)
C
      DO 7 L = 1,NC
      N = NV(L) - 1
      DO 7 I = 1,NSTEP
      DO 5 J = 1,N
      IF (T(I) .LT. X(L,J))  GO TO  31
    5 CONTINUE
      J = N
   31 TT = T(I)
      IF (KI .EQ. 2) TT = ALOG10(TT)
    7 V(L,I) = A(L,J)*TT  + B(L,J)
      RETURN
```

```
      SUBROUTINE STEP(KK, NN, TSTEP, NT, T1, TN, T, NSTEP)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THE ROUTINE GENERATES STEPS IN LINEAR OR LOGARITHMIC INCREMENT .
C
C
C       KK       = SWITCH     KK = 1     STEP INCREASE OF VALUES
C                             KK = 2     LOGARITHMIC INCREASE OF VALUES
C       NN       = NUMBER OF STEPS   OR NUMBER OF VALUES IN EACH 10
C       TSTEP    = LARGEST VALUE IN EACH STEP
C       NT       = NUMBER OF VALUES IN EACH STEP
C       T1       = FIRST VALUE IN LOG-STEP
C       TN       = LAST  VALUE IN LOG-STEP
C       T        = VALUES GENERATED
C       NSTEP    = NUMBER OF VALUES
C
C   B
C   CODED PER B SCHNABEL SEPT. 1970
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      DIMENSION T(200), TSTEP(10), NT(10)
C
      GO TO (1, 2), KK
    1 K = 1
      T(1) = 0.
      SAVE = 0.
      DO 11 N = 1,NN
      M = NT(N)
      STEP = (TSTEP(N) - SAVE)/FLOAT(M)
      SAVE = TSTEP(N)
      DO 11 I = 1,M
      K = K + 1
   11 T(K) = T(K-1) + STEP
      NSTEP = K
      RETURN
    2 NST = ALOG10(T1)
      IF (T1.LT. 1.) NST = NST - 1
      STEP = 1./NN
      K = 1
      TA = 10.**FLOAT(NST)
      T(1) = TA
      DO 22 J = 1,NN
      K = K + 1
      T(K) = TA*10.**(STEP*FLOAT(J))
      IF (T(K) .GT. T1) GO TO 221
   22 CONTINUE
  221 TA = T(K-1)
      K = 1
  2.1 DO 21 J = 1,NN
      K = K + 1
      T(K) = TA*10.**(STEP*FLOAT(J))
      IF (T(K).GT.TN)  GO TO 212
   21 CONTINUE
      TA = TA*10.
      GO TO 211
  212 NSTEP = K
      RETURN
      END
```

```
      SUBROUTINE REDUCE(IPR,X,AX,LL)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C   THIS ROUTINE INCREASES TIME INTERVAL AND REDUCES NUMBER OF VALUES
C
C
C       IPR   =   DIVIDING FACTOR ON LENGTH OF RECORD
C                 MULTIPLICATION FACTOR ON TIMESTEP
C                 MUST BE A POWER OF 2.
C       DT    =   TIMESTEP IN SEC.
C       DF    =   FREQUENCY STEP IN C/SEC.
C       NA    =   NUMBER OF POINTS USED IN FOURIER TRANSFORM
C       X     =   FOURIER TRANSFORM OF OBJECT MOTION
C       AX    =   FOURIER TRANSFORM OF COMPUTED MOTIONS
C
C
C   CODED BY PER B. SCHNABEL DEC. 1970.
C   MODIFIED SEPT. 1971
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER TITLE
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, NA , MMA, DF,MX
      COMPLEX X, AX
      DIMENSION X( 00), AX(3, 40), LL(3)
      F1 = .5/DT
      FA = FLOAT(IPR)
      DT = DT*FA
      NA = NA/IPR
      MMA = MMA/IPR
      NA2 = NA + 2
      MFOLD = NA2/2
      N = MFOLD + 1
      DO 11 I = MFOLD,N
      X(I) = 0.
C
      DO 11 L = 1,3
      IF (LL(L).LE.0) GO TO 12
      AX(L,I) = 0.
   12 CONTINUE
      MFOLD = MFOLD + 1
      F2 = .5/DT
      PRINT 1000,F1,F2,DT, NA
      FMX = FLOAT(MA)
      MX = ALOG(FLOAT(MA)/ALOG(2.))-1.
      IF (MA.GT.2**(MX+1)) MX = MX+1
      RETURN
 1000 FORMAT(  20H  FREQUENCIES FROM  F6.2, 3H TO F6.2,14H C/S  ARE ZER
     1OED.  /
     221H NEW TIMESTEP = F7.4/20H NUMBER OF VALUES = I5//)
      END
```

```
      SUBROUTINE INCREI(PR,X,AX,LL)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C   THIS ROUTINE INCREASES NUMBER OF POINTS IN THE RECORD
C   BY DECREASING TIMESTEP
C
C
C        IPR    =   MULTIPLYING FACTOR ON LENGTH OF PRECORD
C                   MUST BE A POWER OF 2.
C        DT     =   TIMESTEP IN SEC.
C        DF     =   FREQUENCY STEP IN C/SEC.
C        MA     =   NUMBER OF POINTS USED IN FOURIER TRANSFORM
C        X      =   FOURIER TRANSFORM OF OBJECT MOTION
C        AX     =   FOURIER TRANSFORM OF COMPUTED MOTIONS
C
C
C   CODED BY PER B. SCHNABEL DEC. 1973.
C   MODIFIED OCT.  1971
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMPLEX X, AX
      DIMENSION X( 60), AX(3, 64), LL(3)
C
      P1 = .5/DT
      FR = FLOAT(IPR)
      DT = DT/FR
      N = MFOLD- 1
      MA = MA*IPR
      MMA = MMA*IPR
      MA2 = MA + 2
      MFOLD = MA2/2
      MFOLJ = MFOLD + 1
      DO 10 I = N, MFOLD
      X(I) = 0.
      DO 10 L = 1,3
   10 AX(L,I) = 0.
      P2 = .5/DT
      PRINT 1000,P1,P2,DT, MA
      FMA = FLOAT(MA)
      MX = ALOG10(FMA)/ALOG10(2.)+1.
      IF (MA.LT.2**(MX+1)) MX = MX+1
 1000 FORMAT(27H  FREQUENCIES ADDED FROM  F6.2,3H TO F6.2/
     1 4H NEW TIMESTEP = F5.4/19H NUMBER OF VALUES = I5//)
      RETURN
      END
```

```
      SUBROUTINE PLOT (N,M,V,A,ABSIS,ID,XSCALE,MA,MA1)
C
C  PRINTER PLOTTING OF UP TO 9 FUNCTIONS ON THE SAME GRAPH
C  FOLLOWED BY TABULATION OF THE SAME FUNCTIONS
C
C  CODED BY JOHN LYSMER  -  AUGUST 1970
C
C  ARGUMENTS
C     N          = NUMBER OF CURVES ON THE GRAPH  -  MUST BE .LE. MA
C     M          = NUMBER OF POINTS PER CURVE  -  MUST BE .LE. MA
C     V(M)       = VECTOR CONTAINING THE ABSISSAS  -  MAX(ABS(V(I)))=999.
C     A(N,M)     = ROW I CONTAINS ORDINATES OF CURVE I
C     ABSIS(10)= IDENTIFICATION FOR ABSISSA (10A6)
C     ID(N,10) = ROW I CONTAINS IDENTIFICATION FOR CURVE I  (10A6)
C     SCALE      = ORDINATE CORRESPONDING TO 100 PER CENT ON GRAPH
C                  SCALE IS AUTOMATICALLY INCREASED TO THE VALUE
C                  MAX(ABS(A(I,J))) IF SCALE IS SMALLER THAN THIS VALUE
C     MA         = DIMENSION OF 1ST SUBSCRIPT OF A  -  MUST BE .LE. 9
C     MA         = DIMENSION OF 2ND SUBSCRIPT OF A  -  NO LIMIT
C
C  NOTE  -  SKIP TO TOP OF NEW PAGE BEFORE CALLING THIS ROUTINE
C
C**********
C
      DIMENSION V(1),A(MA,MA1),ABSIS(10),ID( 9,10)
      DIMENSION LINE(101),NUMBER(9)
      INTEGER X,BLANK,DOT
      DATA X,BLANK,DOT/1HX,1H ,1H./
      DATA (NUMBER(I),I=1,9)/1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9/
C
C**********
C
      SCALE = XSCALE
      AMAX=0.
      AMIN=0.
C
      DO 1 I=1,N
      DO 1 J=1,M
      AIJ=A(I,J)
      IF(AIJ.GT.AMAX) AMAX=AIJ
      IF(AIJ.LT.AMIN) AMIN=AIJ
    1 CONTINUE
      IF(SCALE.LT.AMAX) SCALE =AMAX
      IF(SCALE.LT.ABS(AMIN)) SCALE=ABS(AMIN)
C
      PRINT 1002,SCALE
      IF(AMIN) 2,3,3
    2 PRINT 1003
      GO TO 4
    3 PRINT 1004
    4 PRINT 1005
C
      DO 5 I=1,M
C
      DO 6 J=1,101
      LINE(J)=BLANK
      IF(J.EQ.1.OR.J.EQ.4) LINE(J)=DOT
    6 CONTINUE
      IF(AMIN) 7,8,8
    7 LINE(51)=DOT
    8 LINE(1)=DOT
```

```
      LINE(I,K)=[illegible]
C
    9 DO 13 J=1,N
      [illegible]
      [illegible]
    3 [illegible]
      [illegible]
      [illegible]
      IF(LINE(INDEX).EQ.[illegible]) GO TO 13
      IF(LINE(INDEX).EQ.[illegible]) GO TO 13
      LINE(INDEX)=[illegible]
      GO TO 10
   13 LINE(INDEX)=[illegible]
   10 CONTINUE
      PRINT 1006,[illegible]
    9 CONTINUE
C
      PRINT 1005
      PRINT 1007,[illegible]
C
      DO 14 [illegible]
      PRINT 1008,[illegible]
   14 CONTINUE
      PRINT 1000
      PRINT 1009,[illegible]
C
      DO 19 [illegible]
      PRINT 1010,[illegible]
   19 CONTINUE
      RETURN
 1000 FORMAT([illegible])
 1002 FORMAT([illegible] PER CENT [illegible]
 1003 FORMAT([illegible] PER CENT)
     1 [illegible]
 1004 FORMAT([illegible] PER CENT)
     2. [illegible]
 1005 FORMAT([illegible]
 1006 FORMAT([illegible]
 1007 FORMAT([illegible]
 1008 FORMAT([illegible]
 1009 FORMAT([illegible]
 1010 FORMAT([illegible]
C
      END
```

```
      SUBROUTINE AMP( [illegible] )
C
C . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C
C  THIS ROUTINE COMPUTES THE AMPLIFICATION SPECTRUM BETWEEN ANY TWO
C  LAYERS
C
C       [illegible]  = NUMBER OF SOIL LAYERS EXCLUDING ROCK
C       [illegible]  = NUMBER OF SUBLAYER FROM WHICH AMPLIFICATION IS COMP.
C       [illegible]  = SUBLAYER TYPE
C                        0 - OUTCROPPING LAYER
C                        1 - LAYER WITHIN PROFILE
C                    = NUMBER OF SUBLAYER TO WHICH AMPLIFICATION IS COMP.
C       LL           = SUBLAYER TYPE
C       LT               0 - OUTCROPPING LAYER
C                        1 - LAYER WITHIN PROFILE
C       [illegible]  = 0 NO PLOTTING
C                      1 PLOT ALL AMP. FUNCTIONS SINCE LAST PLOTTING
C       [illegible]  = FREQUENCY STEPS IN AMP. FUNCTION
C       [illegible]  = CURVE NUMBER IN PLOTTING
C       ID           = IDENTIFICATION
C
C  CODED [illegible]   FEB. 1972
C . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C
      COMPLEX [illegible]
      COMPLEX [illegible]
      DIMENSION [illegible]
      DIMENSION [illegible]
      COMMON /SOILS/ [illegible]
      COMMON /[illegible]/ [illegible]
      COMMON /[illegible]/ [illegible]
      DATA [illegible] CYCLE. [illegible]/SEC.. [illegible]
C
C
      [illegible] = CMPLX(0.,0.)
      [illegible] = 0.
      [illegible] = 1.
      DO 10 I = 2,[illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      DO 101 [illegible]
      IF [illegible] GO TO 102
      [illegible]
      IF [illegible]
  102 IF [illegible] GO TO 11
      [illegible]
      IF [illegible]
   11 [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
  101 CONTINUE
      IF [illegible] GO TO 103
      [illegible]
```

```
      IF (INT.EQ.0) AIN = 2.*E
 195  IF (LL   .NE.N1+1) GO TO 21
      AA    = 2 * PP
      IF (LT.EQ.3)  AA = 2.*E
  21  STIMA(I) = CABS(AA/AIN)
  19  CONTINUE
      DO 23 I = 1,200
  23  T(I) = DF*FLOAT(I-1)
      AMAX = 0.
      DO 22 I = 1,200
      IF (STIMA(I) .LT.  AMAX) GO TO 22
      TMAX = T(I)
      AMAX = STIMA(I)
  22  CONTINUE
      IF (NA.LT.9) NA=NA+1
      PERIOD = 1./TMAX
      IF (TMAX.LT. .00011)  PRINT 1001,AMAX, TMAX
      IF (TMAX.GT. .00011)  PRINT 1001,AMAX, TMAX,PERIOD
      IF (KPL.EQ.3) RETURN
      PRINT 1000
      N = NA-1
      CALL PLCTRM (200,T,ST,46STS,10,0.,9,200)
      NA = 1
      RETURN
1000  FORMAT(33H1  PLOT OF AMPLIFICATION SPECTRA  //)
1001  FORMAT(25H MAXIMUM AMPLIFICATION =  F6.2/
    1 25H FOR FREQUENCY            = F6.2, 7H C/SEC. /
    1 25H     PERIOD               =  F6.2, 5H SEC. /)
      END
```

```
      SUBROUTINE FFT (A,M,INV,S,IFSET,IFERR)
      DIMENSION A(1),INV(1),S(1),M(3),N(3),NP(3),W(2),W2(2),W3(2)
      EQUIVALENCE (N1,N(1)), (N2,N(2)), (N3,N(3))
13    IF (IABS(IFSET)-1) 613,613,20
610   MT=MAX0(M(1),M(2),M(3))-2
      MT=MAX0(2,MT)
      IF (MT-20) 630,630,620
620   IFERR=1
      GO TO 603
630   IFERR=0
      NT=2**MT
      NTV2=NT/2
      THETA=.7853981634
      JSTEP=NT
      JDIF=NTV2
      S(JDIF)=SIN(THETA)
      DO 660 L=2,MT
      THETA=THETA/2.
      JSTEP2=JSTEP
      JSTEP=JDIF
      JDIF=JSTEP/2
      S(JDIF)=SIN(THETA)
      JC1=NT-JDIF
      S(JC1)=COS(THETA)
      JLAST=NT-JSTEP2
      IF (JLAST-JSTEP) 660,640,640
643   DO 650 J=JSTEP,JLAST,JSTEP
      JC=NT-J
      JD=J+JDIF
650   S(JD)=S(J)*S(JC1)+S(JDIF)*S(JC)
660   CONTINUE
C
C     SET UP INV(J) TABLE
      MTLEXP=NTV2
      LM1EXP=1
      INV(1)=0
      DO 693 L=1,MT
      INV(LM1EXP+1)=MTLEXP
      DO 673 J=2,LM1EXP
      JJ=J+LM1EXP
670   INV(JJ)=INV(J)+MTLEXP
      MTLEXP=MTLEXP/2
690   LM1EXP=LM1EXP*2
      IF (IFSET) 23,633,23
20    MTT=MAX0(M(1),M(2),M(3))-2
      ROOT2=SQRT(2.)
      IF (MTT-MT) 43,43,33
30    IFERR=1
      PRINT 1000
      STOP
 1000 FORMAT(31H --- ERROR IN FOURIER TRANSFORM  )
43    IFERR=0
      M1=M(1)
      M2=M(2)
      M3=M(3)
      N1=2**M1
      N2=2**M2
      N3=2**M3
      IF (IFSET) 90,90,73
90    NX=N1*N2*N3
      FN=NX
```

```
      IF (I3C) 240,230,220
220   W3(1)=S(I3C)
      W3(2)=S(I3)
      GO TO 280
230   W3(1)=3.
      W3(2)=1.
      GO TO 280
240   I3CC=I3C+NT
      IF (I3CC) 270,260,250
250   I3C=-I3C
      W3(1)=-S(I3C)
      W3(2)=S(I3CC)
      GO TO 280
260   W3(1)=-1.
      W3(2)=3.
      GO TO 280
270   I3CCC=NT+I3CC
      I3CC=-I3CC
      W3(1)=-S(I3CCC)
      W3(2)=-S(I3CC)
280   ILAST=IL+JJ
      DO 290 I=JJ,ILAST,IDIF
      KLAST=KL+I
      DO 290 K=I,KLAST,2
      K1=K+KBIT
      K2=K1+KBIT
      K3=K2+KBIT
      R=A(K2)*W2(1)-A(K2+1)*W2(2)
      T=A(K2)*W2(2)+A(K2+1)*W2(1)
      A(K2)=A(K)-R
      A(K)=A(K)+R
      A(K2+1)=A(K+1)-T
      A(K+1)=A(K+1)+T
      R=A(K3)*W3(1)-A(K3+1)*W3(2)
      T=A(K3)*W3(2)+A(K3+1)*W3(1)
      AWR=A(K1)*W1(1)-A(K1+1)*W1(2)
      AWI=A(K1)*W1(2)+A(K1+1)*W1(1)
      A(K3)=AWR-R
      A(K3+1)=AWI-T
      A(K1)=AWR+R
      A(K1+1)=AWI+T
      T=A(K1)
      A(K1)=A(K)-T
      A(K)=A(K)+T
      T=A(K1+1)
      A(K1+1)=A(K+1)-T
      A(K+1)=A(K+1)+T
      R=-A(K3+1)
      T=A(K3)
      A(K3)=A(K2)-R
      A(K2)=A(K2)+R
      A(K3+1)=A(K2+1)-T
290   A(K2+1)=A(K2+1)+T
300   JJ=JDIF+JJ
310   JLAST=4*JLAST+3
320   CONTINUE
330   CONTINUE
      NTSQ=NT*NT
      N3VNT=N3-NT
      IF (N3-NT) 350,340,340
340   IGO3=1
      N3VNT=N3/NT
      MINN3=NT
      GO TO 360
350   IGO3=2
      N3VNT=1
      NTVN3=NT/N3
      MINN3=N3
360   JJD3=NTSQ/N3
      M2MT=M2-MT
      IF (M2MT) 380,370,370
370   IGO2=1
      N2VNT=N2/NT
      MINN2=NT
      GO TO 390
380   IGO2=2
      N2VNT=1
      NTVN2=NT/N2
      MINN2=N2
390   JJD2=NTSQ/N2
      M1MT=M1-MT
      IF (M1MT) 410,400,400
400   IGO1=1
      N1VNT=N1/NT
      MINN1=NT
      GO TO 420
410   IGO1=2
      N1VNT=1
      NTVN1=NT/N1
      MINN1=N1
420   JJD1=NTSQ/N1
      JJ3=1
      J=1
      DO 570 JPP3=1,N3VNT
      IPP3=INV(JJ3)
      DO 560 JP3=1,MINN3
      GO TO (430,440), IGO3
430   IP3=INV(JP3)*N3VNT
      GO TO 450
440   IP3=INV(JP3)/NTVN3
450   I3=(IPP3+IP3)*N2
      JJ2=1
      DO 550 JPP2=1,N2VNT
      IPP2=INV(JJ2)+I3
      DO 540 JP2=1,MINN2
      GO TO (460,470), IGO2
460   IP2=INV(JP2)*N2VNT
      GO TO 480
470   IP2=INV(JP2)/NTVN2
480   I2=(IPP2+IP2)*N1
      JJ1=1
      DO 530 JPP1=1,N1VNT
      IPP1=INV(JJ1)+I2
      DO 520 JP1=1,MINN1
      GO TO (490,500), IGO1
490   IP1=INV(JP1)*N1VNT
      GO TO 510
500   IP1=INV(JP1)/NTVN1
510   I=2*(IPP1+IP1)+1
      IF (J-I) 520,530,530
520   T=A(I)
      A(I)=A(J)
      A(J)=T
      T=A(I+1)
```

```
      A(I+1)=A(J+1)
      A(J+1)=T
530   CONTINUE
540   J=J+2
550   JJ1=JJ1+JJD1
560   JJ2=JJ2+JJD2
570   JJ3=JJ3+JJD3
      IF (IFSET) 580,600,600
580   DO 590 I=1,NX
590   A(2*I)=-A(2*I)
600   RETURN
      END
```

```
      SUBROUTINE AFFT (A,M,INV,S,IFERR)
      DIMENSION A(1), L(3), INV(1), S(1)
      IFSET=1
      L(1)=M
      L(2)=0
      L(3)=0
      NTOT=2**M
      NTOT2=2*NTOT
      FN=NTOT
      DO 10 I=2,NTOT2,2
10    A(I)=-A(I)
      DO 20 I=1,NTOT2
20    A(I)=A(I)/FN
      CALL FFT (A,L,INV,S,IFSET,IFERR)
C
C     MOVE LAST HALF OF A(J)S DOWN ONE SLOT AND ADD A(N+1) AT BOTTOM TO
C     GIVE ARRAY FOR A1PRIME AND A2PRIME CALCULATION
C
      DO 30 I=1,NTOT,2
      J0=NTOT2+2-I
      A(J0)=A(J0-2)
30    A(J0+1)=A(J0-1)
      A(NTOT2+3)=A(1)
      A(NTOT2+4)=A(2)
C
C     CALCULATE A1PRIMES AND STORE IN FIRST N SLOTS
C     CALCULATE A2PRIMES AND STORE IN SECOND N SLOTS IN REVERSE ORDER
      NO=NTOT+1
      DO 40 I=1,NO,2
      K1=NTOT2-I+4
      AP1RE=.5*(A(I)+A(K1))
      AP2RE=-.5*(A(I+1)+A(K1+1))
      AP1IM=.5*(-A(I+1)+A(K1+1))
      AP2IM=-.5*(A(I)-A(K1))
      A(I)=AP1RE
      A(I+1)=AP1IM
      A(K1)=AP2RE
40    A(K1+1)=AP2IM
      NT0=NTOT/2
      NT=NT0+1
      DEL=3.1415927/FLOAT(NTOT)
      SS=SIN(DEL)
      SC=COS(DEL)
      SI=0.0
      CO=1.0
C
C     COMPUTE C(J)S FOR J=0 THRU J=N
      DO 90 I=1,NT
      K6=NTOT2-2*I+5
      AP2RE=A(K6)*CO+A(K6+1)*SI
      AP2IM=-A(K6)*SI+A(K6+1)*CO
      CIRE=.5*(A(2*I-1)+AP2RE)
      CIIM=.5*(A(2*I)+AP2IM)
      CNIRE=.5*(A(2*I-1)-AP2RE)
      CNIIM=.5*(A(2*I)-AP2IM)
      A(2*I-1)=CIRE
      A(2*I)=CIIM
      A(K6)=CNIRE
      A(K6+1)=-CNIIM
      SIS=SI
      SI=SI*SC+CO*SS
```

```
      SUBROUTINE RFSN(A,M,INV,S,IFERR)
      DIMENSION A(1),L(3),INV(1),S(1)
      L(1)=M
      L(2)=0
      L(3)=0
      NTOT=2**M
      IFSET=-1
      NTOT2=NTOT+NTOT
      FN=NTOT
      NTOT3=NTOT2+4
      DO 70 I=3,NTOT2,2
      A(I)=.5* A(I)
   70 A(I+1)= .5*A(I+1)
      DO 80 I=1,NTOT,2
      K0=NTOT2+2-I
      A(K0)= A(K0-2)
   80 A(K0+1)=A(K0-1)
      NTO=NTOT/ 2
      NT=NTO+1
      DEL=3.14159265/FN
      SS= SIN(DEL)
      SC= COS(DEL)
      SI=0.
      CO =1.0
      DO 93 I=1,NT
      K6=NTOT2-2*I+5
      CIRE= A(2*I-1) + A(K6)
      CIIM=A(2*I)-A(K6+1)
      CNIRE=(-SI*(A(2*I)+A(K6+1))-CO*(A(2*I-1)-A(K6)))
      IF(SI)62,61,62
   62 CNIIM=(A(2*I-1)-A(K6)-CO*CNIRE)/SI
      GO TO 63
   61 CNIIM=0.
   63 A(2*I-1)=CIRE
      A(2*I)=CIIM
      A(K6)=CNIRE
      A(K6+1)=CNIIM
      SIS=SI
      SI=SI*SC+CO*SS
   93 CO=CO*SC-SIS*SS
      KD=NTOT+1
      DO 40 I=1,KD,2
      K1=NTOT2-I+4
      AP1RE=A(I)-A(K1-1)
      AP2RE=-(A(I+1)+A(K1))
      AP1IM=A(I)+A(K1-1)
      AP2IM=A(I+1)-A(K1)
      A(I)=AP1RE
      A(I+1)=AP2RE
      A(K1)=AP1IM
   40 A(K1+1)=AP2IM
      NTOP=NTOT2+2
      NTOO=NTOT-1
      A(1)=A(NTOT2+3)
      A(2)=A(NTOT2+4)
   21 DO 22 I=NTOO,NTOP,2
      A(I)=A(I+2)
   22 A(I+1)=A(I+3)
      CALL RFT(A,L,INV,S,IFSET,IFERR)
      DO 23 I=1,NTOT2
   23 A(I)=A(I)*FN
```

```
   93     CO=CO*SC-SIS*SS
C
C         SHIFT C(J)'S FOR J=N/2+1 TO J=N UP ONE SLOT
          DO 60 I=1,NTOT,2
          K0=NTOT-I+1
          A(K0-2)=A(K0)
   60     A(K0-1)=A(K0+1)
          DO 70 I=3,NTOT2,2
          A(I)=2.*A(I)
   70     A(I+1)= 2.*A(I+1)
          RETURN
          END
```

```
      DO 10 I=2,NTOT2,2
   10 A(I)=-A(I)
      RETURN
      END
      END
```

ACKNOWLEDGEMENTS

The development of the computer program SHAKE was conducted as part of a study of "Soil and Foundation Response During Earthquakes" sponsored by the National Science Foundation. The authors are most grateful for this support and for valuable suggestions from Professor W. N. Houston in reviewing the manuscript.

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SUPPLEMENT TO COMPUTER PROGRAM SHAKE*

by

T. Udaka and J. Lysmer

September 1973

Suggested corrections are shown framed on the attached segments of subroutines SHAKIT, EARTHQ, CXSOIL, MOTION, STRT, UTPR, RESP, STRAIN, REDUCE, FFT, RFFT and RFSN of program SHAKE.

The purpose of these changes are:

1. To decrease the execution time by up to 50% depending on the type of problem to be solved.

2. To redefine the complex modulus from $G^* = G(1 + 2i\beta)$ to $G^* = G(1 - 2\beta^2 + i\, 2\beta\sqrt{1 - \beta^2})$.

   (This change only influences subroutine CXSOIL)

Input and output formats are unchanged by these corrections and response values will differ only slightly from those in the published* test example, see page 16.

---

*"SHAKE A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites," by P. B. Schnabel, J. Lysmer, and H. B. Seed, Report No. EERC 72-12, Earthquake Engineering Research Center, University of California, Berkeley, December 1972.

```
C     PROGRAM SHAKE2(INPUT, OUTPUT, PUNCH)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C
C   THIS PROGRAM COMPUTES RESPONSE IN A HORISONTALLY LAYERED SEMI-
C   INFINITE SYSTEM SUBJECTED TO VERTICALLY TRAVELLING SHEAR WAVES
C   THE METHOD IS BASED ON THE CONTINOUS SOLUTION TO THE SHEAR WAVE
C   EQUATION
C
C
C   PROGRAMMED BY  PER B SCHNABEL RESEARCH ASSISTANT
C                  JOHN LYSMER    ASSOCIATE PROFESSOR
C
C                                 GEOTECHNICAL ENGINEERING
C                                 UNIVERSITY OF CALIFORNIA
C                                 BERKELEY
C
C
C   PROGRAM VERSION      SHAKE1   JANUARY 1972
C                        SHAKE2   APRIL 1972
C                                 JUNE 1972
C                                 CHANGE - OPTION 7 CORRECTED
C                                        - SUBROUTINES STEPG AND FFT
C                                          ADAPTED TO UNIVAC COMPUTERS
C                                 DECEMBER 1972
C                                 CHANGE - SUBROUTINES DRCTSP AND STRAIN
C                                 SEPTEMBER 1973
C                                 CHANGE - SUBROUTINES SHAKIT,EARTHQ,
C                                          CXSOIL,MOTION,STRT,STRAIN
C                                          REDUCE,UTPR,RESP,FFT,RFFT AND
C                                          RFSN.
C                                          EXECUTION TIME REDUCED BY UP
C                                          TO 50 PERCENT.
C                                          COMPLEX SHEAR MODULUS CHANGED
C                                          FROM G(1.+I*2.*BETA)
C                                          TO G(1.-2.*BETA**2+I*2.*BETA*
C                                             SQRT(1.-BETA**2))
C
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C
C
C   DEFINITIONS
C        INPUT MOTION       = MOTION READ IN FROM CARDS
C        OBJECT MOTION      = MOTION USED AS BASIS FOR COMPUTING NEW
C                             MOTIONS IN A SOIL PROFILE
C        COMPUTED MOTION    = MOTION COMPUTED ANYWHERE IN A GIVEN SOIL
C                             SOIL PROFILE FROM A GIVEN OBJECT MOTION
```

```
      SUBROUTINE SHAKIT(X,AX,AA,S,INV)
C
C
C . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
C
C     THIS ROUTINE CALLS THE DIFFERENT SEQUENCES OF OPERATION.15 DIFFERENT
C     OPERATIONS CAN BE PERFORMED AS LISTED BELOW.
```

[redacted]

```
      INTEGER TITLE,TP
      COMPLEX X, AX
      COMPLEX G, V, PLUS, MINUS
      DIMENSION ABSIS(10), ABSPR(10),AHSCH(10)
      DIMENSION LL(3), LT(3),LNSW(3)
      DIMENSION LLL(2), LLGS(2),LLPCH(2),LLPL(2),SK(2),LNV(2)
      DIMENSION X(300),AX(3,270),AA(2,550),S(70),INV(70)
      DIMENSION LLS(15), LTS(15), LPS(15),LP(3)
      DIMENSION IDAMP(9,11)
      DIMENSION MMM(3)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON /SOILA/ IDNT(6),BL(20),GL(20),FACT(20),H(20),R(20),RF(20)
      COMMON /SOILB/ FAC(20), WL(20), TP(20), DEPTH(20), WEIGHT(20)
      COMMON /SOILC/ MSOIL,MWL
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
      COMMON /CCG/ ID(9,11), T(2048)
      COMMON/FROUT/ NOUT,NZERO

      DATA IBLANK /6H      /
      DATA (ABSIS(I),I=1,10)/6H TIME ,6HIN SEC ,6HONDS  ,7*6H      /
```

[redacted]

```
   71 DO 74 I = 1,MFOLD
   74 X(I) = X(I)*XF
      NEW = IN
   73 IN = NEW
      PRINT 7000, NEW , XF,DT, DTNEW
      IF(IN.NE.1) GO TO 76
      DO 77 II=1,MFOLD
      AX(1,II)=X(II)
   77 CONTINUE
   76 CONTINUE
      DT = DTNEW
      DF = 1./(MA*DT)
      GO TO 101
```

[redacted]

```
   10 PRINT 1010,KK
      READ 1000, IFR
      CALL REDUCE(IFR,X,AX,LL)
      MMM(1)=MV
      MMM(2)=0
      MMM(3)=0
      CALL FFT(X,MMM,INV,S,0,IFERR)
      GO TO 101
C
C * * * * * * * * * *
   11 PRINT 1101,KK
      READ 1000, IFR
      CALL INCR(IFR,X,AX,LL)
      MMM(1)=MV
      MMM(2)=0
      MMM(3)=0
      CALL FFT(X,MMM,INV,S,0,IFERR)
      GO TO 101
C
C * * * * * * * * * *

   14 PRINT 1606,KK
      READ 1000, NSKIP, NN, NSW
      NP = NP + 1
      CALL RFSN(X,MX,INV,S,IFERR,-2)
      IF (NN.LE.0)  NN = MMA/NSKIP
      IF (NN.GT.2049)  NN = 2049
      NN =  NN*NSKIP
      N = 0
      DO 136 I=1, NN, NSKIP
      N = N + 1
      T(N) = FLOAT(I-1)*DT
  136 CONTINUE
      N = 0
      M = NN/2
      DO 130 I = 1,M
      N = N + 1
      AA(NP,N) = REAL(X(I))
      N = N + 1
      AA(NP,N) = AIMAG(X(I))
  130 CONTINUE
      IF  (NSKIP.EQ.1) GO TO 135
      N = 0
      DO 134 I = 1,NN ,NSKIP
      N = N + 1
      AA(NP,N) = AA(NP,I)
  134 CONTINUE
  135 CALL RFFT(X,MX,INV,S,IFERR,2)
      DO 131 I = 1,5
  131 ID(NP,I) = TITLE(I)
      DO 132 I = 6,11
      ID(NP,I) = IDNT(I-5)
      IF (NSW.EQ.0)  ID(NP,I)  = IBLANK
  132 CONTINUE
      IF (NSW.EQ.1) GO TO 101
      CALL PLOT(NP, N, T, AA, ABSIS, ID, 0., 2, N)
      NP = 0
      GO TO 101
```

```
      SUBROUTINE EARTHQ(X,AX,AA,S,INV)
C
C*****************************************************************************
C
C     THIS ROUTINE  READS THE MOTION IN THE TIME DOMAIN, ADDS TRAILING
C     ZEROS, SCALES THE VALUES, FIND MAXIMUM VALUE AND VARIOUS PARAMETERS
C     AND TRANSFER THE MOTION INTO THE FREQUENCY DOMAIN.
[redacted]
      INTEGER TITLE
      COMPLEX X, AX
      DIMENSION XR(8)
      DIMENSION X(300),AX(3,270),AA(2,550),S(70),INV(70)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF, MX
      COMMON/FRCUT/ NCUT,NZERO
C
      PI2 = 6.28
      READ 1001, NV, MA, DT, TITLE
[redacted]
   30 X(I) = X(I)*XF
      XMAX = XM*XF
      TMAX = FLOAT(NXMAX-1)*DT
      PRINT 2014,XM,TMAX,XF,XMAX
C
      CALL FFFT(X,MX,INV,S,IFERR,1)
C     X(1) = 0.
C
C     REMOVE FREQUENCIES ABOVE FMAX AND FIND MAX. ACC. OF
C
      FREQ = 0.
      SXX = 0.
      SFX = 0.
      NCUT=0
      DO 33 I = 1,MFOLD
      IF(FREQ.LE.FMAX) GO TO 34
      NCUT=NCUT+1
      X(I)=0.0
   34 CONTINUE
      XA = CABS(X(I))
      SXX= SXX + XA*XA
      SFX = SFX + FREQ*XA*XA
      AX(1,I) = X(I)
      FREQ = FREQ + DF
   33 CONTINUE
      SFX = SFX/SXX
      NCUT=MFOLD-NCUT
      NZERO=NCUT+1
      PRINT 2005,SFX
      IF (FMAX.GT.FREQ) RETURN
      CALL RFSN(X,MX,INV,S,IFERR,-2)
      CALL XMX(X,MA,XM,NXMAX)
      DO 72 I = 1,MFOLD
   72 X(I) = AX(1,I)
      PRINT 2001,XM,FMAX
```

```
      SUBROUTINE CXSOIL(N1)
C
C*****************************************************************************
C
C    THIS ROUTINE CALCULATES THE COMPLEX SOIL PROPERTIES AND TRANSFER
C    FUNCTIONS FOR THE LAYERS
C
C          N1        = NUMBER OF SOIL LAYERS
C          BL        = RATIO OF CRITICAL DAMPING
C          GL        = SHEAR MODULUS
C          R         = DENSITY
C          G         = COMPLEX SHEAR MODULUS
C          V         = COMPLEX SHEAR WAVE VELOCITY
C          PLUS      = COMPLEX TRANSFER FUNCTION
C          MINUS     = COMPLEX TRANSFER FUNCTION
C
C    CODED BY PER B SCHNABEL OCT 1971
C
C*****************************************************************************
C
      COMPLEX G, V, PLUS, MINUS, MU
      COMMON /SOILA/ IDNT(6),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
C
      N = N1 + 1
      DO 1 I = 1,N
      GIMAG=2.*BL(I)*GL(I)*SQRT(1.-BL(I)*BL(I))
      GREAL=GL(I)*(1.-2.*BL(I)*BL(I))
      G(I)=CMPLX(GREAL,GIMAG)
      V(I) = CSQRT(G(I)/R(I))
    1 CONTINUE
      DO 2 I = 1,N1
      J = I + 1
      MU = CSQRT(R(I)/R(J)*G(I)/G(J))
      PLUS(I) = (1. + MU)/2.
      MINUS(I)= (1. - MU)/2.
    2 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MOTION(N1,IN,INT,LL,LT, X,AX)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     THIS ROUTINE CALCULATES THE MOTION IN ANY TWO SOIL LAYERS OR IN
C     ROCK FROM MOTION GIVEN IN ANY LAYER OR IN ROCK
C
C        N1       = NUMBER OF SOIL LAYERS EXCLUDING ROCK
C        IN       = NUMBER OF LAYER WHERE OBJECT MOTION IS GIVEN
C        INT      = MOTION TYPE
C                   IF EQ 0      OUTCROPPING LAYER
C        LL()     = NUMBER OF LAYERS WHERE OUTPUT MOTION IS WANTED
C                   MAX  3 LAYERS
C        LT()     = MOTION TYPE
C                   0 - OUTCROPPING LAYER
C                   1 - LAYER WITIN PROFILE
C        X()      = OBJECT MOTION
C        AX()     = OUTPUT MOTION
C
C
C     CODED BY PER B SCHNABEL  OCT 1970
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER LL(3), LT(3)
      INTEGER TITLE
      COMPLEX AA(3)
      COMPLEX X, AX
      COMPLEX   G, V, PLUS, MINUS
      COMPLEX E, F, EE, FF, A, EX, AIN, IPI2
      DIMENSION X(300),AX(3,270),           S(70),INV(70)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON /SOILA/ IDNT(6),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
      COMMON/FRCUT/ NCUT,NZERO
C
C
      IPI2 = CMPLX(0., 6.28)
      DO 20 L = 1,3
      IF (LL(L) .GT. 0) AX(L,1) = X(1)
      IF(NCUT.EQ.MFOLD) GO TO 20
      DO 30 I=NZERO,MFOLD
      AX(L,I)=CMPLX(0.,0.)
   30 CONTINUE
   20 CONTINUE
      FREQ = 0.
      DO 19 I=2,NCUT
      E = 1.
      FF = 1.
      FREQ = FREQ + DF
      A = FREQ*IPI2
      DO 191 K = 1,N1
      IF (K.NE.IN) GO TO 192
```

```
      SUBROUTINE STRT( IT,N1,DGMAX,PRMUL,X,AX,AA,SF,INV)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     THIS ROUTINE CALCULATES STRAIN IN THE MIDDLE OF EACH LAYER AND FIN
C     NEW SOIL PROPERTIES COMPATIBLE WITH THE STRAINS
C
[redacted]

      COMMON /SOILDG/ S(9,20), AS(9,20), BS(9,20), NV(9)
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
      COMMON/FRCUT/ NCUT,NZERO
      DIMENSION TMAX(20),           EMAX(20),STR(20)
      DIMENSION X( 69), AX(3, 64), AA(2,128),SF(10), INV(10)
C
      DO 43 I = 1,MFOLD
      AA(1,I) = REAL(X(I))
   43 AA(2,I) = AIMAG(X(I))
      DO 1  I = 1,MFOLD
      AX(2,I) = AX(1,I)/2.
    1 AX(3,I) = AX(2,I)
      PI2=6.283
      IPI2=CMPLX(0.,PI2)
      GT = 32.2
      DO 2 K = 1,N1
      FREQ = 0.
      X(1) = 0.
      FF = GT/(IPI2*V(K))
      EE = H(K)/2.*IPI2/V(K)
      DO 20 I=2,NCUT
      FREQ = FREQ + DF

      EX = CEXP(FREQ*EE)
      X(I) = (AX(2,I)*EX - AX(3,I)/EX)*FF/FREQ
      EX = EX*EX
      E = AX(2,I)*EX
      F = AX(3,I)/EX
      AX(2,I)= PLUS(K)*E + MINUS(K)*F
      AX(3,I)= PLUS(K)*F + MINUS(K)*E
   20 CONTINUE
      EMAX(K) = 0.
      IF(NCUT.EQ.MFOLD) GO TO 22
      DO 122 II=NZERO,MFOLD
      X(II)=CMPLX(0.,0.)
  122 CONTINUE
   22 CONTINUE
C
C     DETERMINE MAX. STRAIN BY INVERTING FOURIER TRANSFORM OF STRAIN
C     INTO THE TIME DOMAIN
C
      CALL RFSN(X,MX,INV,SF,IFERR,-2)
      CALL XMX(X,MA,XMAX,NXMAX)
C
```

```
      SUBROUTINE UTPR(KK,DPTH,LS,K2,LH,LT,X,AX,AA,S,INV)
C
C
C*****************************************************************************
C
C     THIS ROUTINE TRANSFERES THE VALUES IN AX(LH, ) INTO THE TIME DOMAIN
C     IN X( ), PRINTS AND PUNCHES OUT THE RESULTS.
C
```

[redacted]

```
C
      FREQ = 0.
      SFX = 0.
      SXX = 0.
C   TRANSFORM VALUES IN X OR IN AX INTO THE TIMEDOMAIN
      DO 24  I = 1,MFOLD
      IF (LS.EQ.0) GO TO 241
      SAVE = X(I)
      X(I) = AX(LS,I)
      AX(LS,I) = SAVE
  241 XA = CABS(X(I))
      SXX= SXX + XA*XA
      SFX =  SFX + XA*FREQ*XA
      FREQ = FREQ + DF
   24 CONTINUE
      SFX = SFX/SXX
C
      CALL RFFT(X,MX,INV,S,IFERR,-2)
C
```

[redacted]

```
      PUNCH 2009,(XR(J),J=1,8),I
      IF (K2 .EQ. 2) PRINT 2019, (XR(J), J = 1,8), I
      NN = 4 + NN
      N = N + 4
   26 CONTINUE
  262 CALL RFFT(X,MX,INV,S,IFERR,2)
      IF (LS.EQ.0)    RETURN
      DO 27 I = 1,MFOLD
      SAVE = AX(LS,I)
      AX(LS,I) = X(I)
   27 X(I) = SAVE
      RETURN
```

```
      SUBROUTINE RESP(LL,LN,LS,NN,X,AX,A,S,INV)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C   THIS PROGRAM READS DATA FOR RESPONSE SPECTRUM ANALYSIS
C   NECESSARY SUBROUTINES     DRCTSP,  CMPMAX, PLOT
C
C        NN       = RESPONSE SPECTRUM NUMBER
C        ND       = NUMBER OF DAMPING VALUES
C        KAV      = SWITCH
C                   EQ 0  ACCELERATION SPECTRUM
C                   EQ 1  VELOCITY SPECTRUM
C                   EQ 2  ACC. AND VEL. SPECTRUM
C        KPL      = SWITCH
C                   EQ 1  PLOT RESPONSE SPECTRA ACCORDING TO KAV
C        KP       = SWITCH
C                   EQ 0  NO PUNCHED OUTPUT
C                   NE 0  PUNCHED OUTPUT ACCORDING TO KAV
C        X        = FOURIER TRANSFORM OF OBJECT MOTION
C        AX       = FOURIER TRANSFORM OF COMPUTED MOTIONS
C        DW       = PERIOD STEPS
C        NM       = NUMBER OF EACH STEP
C        T        = PERIODS WHERE RESPONSE IS TO BE COMPUTED
C
```

[redacted]

```
  101 T(1) = .001
C   SAVE VALUES IN X IN AA
      DO 11 I = 1,MFOLD
      A(1,I) = REAL(X(I))
      A(2,I) = AIMAG(X(I))
      IF (LS.EQ.0) GO TO 11
      X(I) = AX(LS,I)
   11 CONTINUE
C
C   TRANSFORM VALUES IN X OR AX INTO THE TIME DOMAIN
      CALL RFSN(X,MX,INV,S,IFERR,-2)
      DO 13 L = 1,ND
      IF (NN.GE.5)  NN= 0
      NN = NN + 1
      DO 131 I = 1,5
  131 ID(NN,I) = TITLE(I)
      DO 132 I = 6,11
      ID(NN,I) = IDNT(I-5)
      IF (LS.EQ.0) ID(NN,I) = IBLANK
  132 CONTINUE
```

```
      SUBROUTINE STRAIN( LL, LGS, LPCH, LPL,LNV,SK,X,AX,AA,N1,S,INV)
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     THIS SUBROUTINE COMPUTES STRAIN AND/OR STRESS TIME-HISTORY AT THE
C     TOP OF ANY LAYER FOR ACCELERATION HISTORY KNOWN IN ANY LAYER
C     TWO RESPONSE HISTORIES ARE COMPUTED IN ONE RUN
C

      INTEGER TITLE,TP
      COMPLEX X, AX
      COMPLEX G, V, PLUS, MINUS
      COMPLEX E,F,EE, A,AH,IPI2, AE,AF,EX,AI
      DIMENSION ABSIS(10)
      DIMENSION AE(2), AF(2)
      DIMENSION X(1), AX(3,1), AA(2,1),S(1),INV(1)
      DIMENSION  LL(2),  LGS(2), LPCH(2), LPL(2),SK(2),LNV(2)
      COMMON /SOILA/ IDNT(6),BL(20),GL(20),FACT(20),H(20),R(20),BF(20)
      COMMON /SOILB/ FAC(20), WL(20), TP(20), DEPTH(20), WEIGHT(20)
      COMMON /CSOIL/ G(20), V(20), PLUS(20), MINUS(20)
      COMMON /FQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON /CCG/ ID(9,11),T(2049)
      COMMON/FFCUT/ NCUT,NZERO
C
      IPI2 = CMPLX(0.,6.283)
      GT = 32.2
      AX(2,1) = 0.
      AX(3,1) = 0.
      FREQ = 0.
      DATA (ABSIS(I), I=1,10)/6H TIME ,6HIN SEC , 8*6H      /
      AI = GT/IPI2
C
C     STARTING AT THE SURFACE THE STRAIN IS COMPUTED SUCCESSIVELY DOWNWARD
C     FOR EACH FREQUENCY
      DO 1 I=2,NCUT
      E = AX(1,I)/2.

      DO 2 I = 1,MFOLD
    2 AX(1,I) = X(I)
      DO 3 L = 1,2
      IF (LL(L).EQ.0) GO TO 3
      X(1) = 0.
      DO 31 I=2,NCUT
   31 X(I) = AX(L+1,I)
      IF(NCUT.EQ.MFOLD) GO TO 33
      DO 34 II=NZERO,MFOLD
      X(II)=CMPLX(0.,0.)
   34 CONTINUE
   33 CONTINUE
      CALL RFSN(X,MX,INV,S,IFERR,-2)
      DO 32 I =1,MFOLD
      AA(L,2*I-1) =REAL(X(I))*100.
   32 AA(L,2*I) = AIMAG(X(I))*100.
    3 CONTINUE
```

```
      SUBROUTINE REDUCE(IFR,X,AX,LL)
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C    THIS ROUTINE INCREASES TIME INTERVAL AND REDUCES NUMBER OF VALUES
C
C
C         IFR    =    DIVIDING FACTOR ON LENGTH OF FRECORD
C                     MULTIPLICATION FACTOR ON TIMESTEP
C                     MUST BE A POWER OF 2.
C         DT     =    TIMESTEP IN SEC.
C         DF     =    FREQUENCY STEP IN C/SEC.
C         MA     =    NUMBER OF POINTS USED IN FOURIER TRANSFORM
C         X      =    FOURIER TRANSFORM OF OBJECT MOTION
C         AX     =    FOURIER TRANSFORM OF COMPUTED MOTICNS
C
C
C    CODED BY PER B. SCHNABEL DEC. 1970.
C    MODIFIED SEPT. 1971
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER TITLE
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON/FRCUT/ NCUT,NZERO
      COMPLEX X, AX
      DIMENSION X( 68), AX(3, 64), LL(3)
      F1 = .5/DT
      FR = FLOAT(IFR)
      DT = DT*FR
      MA = MA/IFR
      MMA = MMA/IFR
      MA2 = MA + 2
      MFOLD = MA2/2
      N = MFOLD + 1
      DO 12 I = MFOLD,N
      X(I) = 0.
C
      DO 12 L = 1,3
      IF (LL(L).LE.0) GO TO 12
      AX(L,I) = 0.
   12 CONTINUE
      MFOLD = MFOLD + 1
      F2 = .5/DT
      PRINT 1000,F1,F2,DT, MA
      FMA = FLOAT(MA)
      MX = (ALOG10(FMA)/ALOG10(2.))-1.
      IF (MA.LT.2**(MX+1)) MX = MX+1
      IF(NCUT.LE.MFOLD) GO TO 15
      NCUT=MFOLD
   15 CONTINUE
      RETURN
```

```
      SUBPOUTINE FFT (A,M,INV,S,IFSET,IFERP)
      DIMENSION A(1),INV(1),S(1),N(3),M(3),NP(3),W(2),W2(2),W3(2)
      EQUIVALENCE (N1,N(1)), (N2,N(2)), (N3,N(3))
      M1=M(1)
      M2=M(2)
      M3=M(3)
      MTT=M1-2
      MT=MAXO(2,MTT)
      NT=2**MT
10    IF (IABS(IFSET)-1) 610,610,20
610   MT=MAXO(M(1),M(2),M(3))-2
      MT=MAXO(2,MT)
      IF (MT-20) 630,630,620
620   IFERP=1
      GO TO 600
630   IFERP=0


30    IFERP=1
      PRINT 1000
      STOP
 1000 FORMAT(31H --- ERPOR IN FOURIER TRANSFORM  )
40    IFERR=0
C     M1=M(1)
C     M2=M(2)
C     M3=M(3)
      N1=2**M1
      N2=2**M2
      N3=2**M3
      IF (IFSET) 50,50,70
50    NX=N1*N2*N3
      FN=NX
      DO 60 I=1,NX
      A(2*I-1)=A(2*I-1)/FN
60    A(2*I)=-A(2*I)/FN
70    NP(1)=N1*2
      NP(2)=NP(1)*N2
      NP(3)=NP(2)*N3
      DO 330 ID=1,3
      IL=NP(3)-NP(ID)
      IL1=IL+1
```

```
      SUBROUTINE RFFT (A,M,INV,S,IFERR,IFSET)
      DIMENSION A(1), L(3), INV(1), S(1)
      IFSET=1
      L(1)=M
      L(2)=0
      L(3)=0
      NTOT=2**M
      NTOT2= 2*NTOT
      FN=NTOT
      DO 10 I=2,NTOT2,2
10    A(I)=-A(I)
      DO 20 I=1,NTOT2
20    A(I)=A(I)/FN
      CALL FFT (A,L,INV,S,IFSET,IFERR)
C
C     MOVE LAST HALF OF A(J)S DOWN ONE SLOT AND ADD A(N) AT BOTTOM TO
C     GIVE ARRAY FOR A1PRIME AND A2PRIME CALCULATION
C
```

```
      SUBROUTINE RFSN (A,M,INV,S,IFERR,IFSET)
      DIMENSION A(1),L(3),INV(1),S(1)
      L(1)=M
      L(2)=0
      L(3)=0
      NTOT=2**M
      IFSET=-1
      NTOT2=NTOT+NTOT
      NN=NTOT2+2
      A(NN+2)=A(NN)
      A(NN+1)=A(NN-1)
      FN=NTOT
      NTOT3=NTOT2+4
      DO 70 I=3,NTOT2,2
      A(I)=0.5* A(I)
   70 A(I+1)= .5*A(I+1)
      DO 60 I=1,NTOT,2
      KB=NTOT2+2-1
      A(KB)= A(KB-2)
   60 A(KB+1)=A(KB-1)
      NTD=NTOT/ 2
      NT=NTD+1
      DEL=3.14159265/FN
      SS= SIN(DEL)
      SC= COS(DEL)
      SI=0.
      CO =1.0
      DO 50 I=1,NT
```

COMPARISON BETWEEN ORIGINAL AND NEW RESULTS

The redefinition of the complex modulus G^* from

$$G^* = G(1 + 2i\beta)$$

where β is the fraction of critical damping to the improved value

$$G^* = G(1 - 2\beta^2 + 2i\beta\sqrt{1 - \beta^2})$$

slightly changes the response values computed by program SHAKE. The following table shows the influence on maximum accelerations through the profile, see page 50 of the original report*.

Depth	Original Max. Acc.	New Max. Acc.
0.0	0.09377	0.09878
7.0	0.09259	0.09758
20.0	0.05934	0.05942
30.0	0.05487	0.05540
42.0	0.05042	0.05037
62.0	0.04666	0.04667
80.0	0.03195	0.03140
100.0	0.02423	0.02364
120.0	0.01793	0.01763

all other differences observed were of similar or smaller relative magnitude.